JULY 1960

NUCLEONICS

APPLIED RADIATION • ATOMIC POWER • NUCLEAR ENGINEERING

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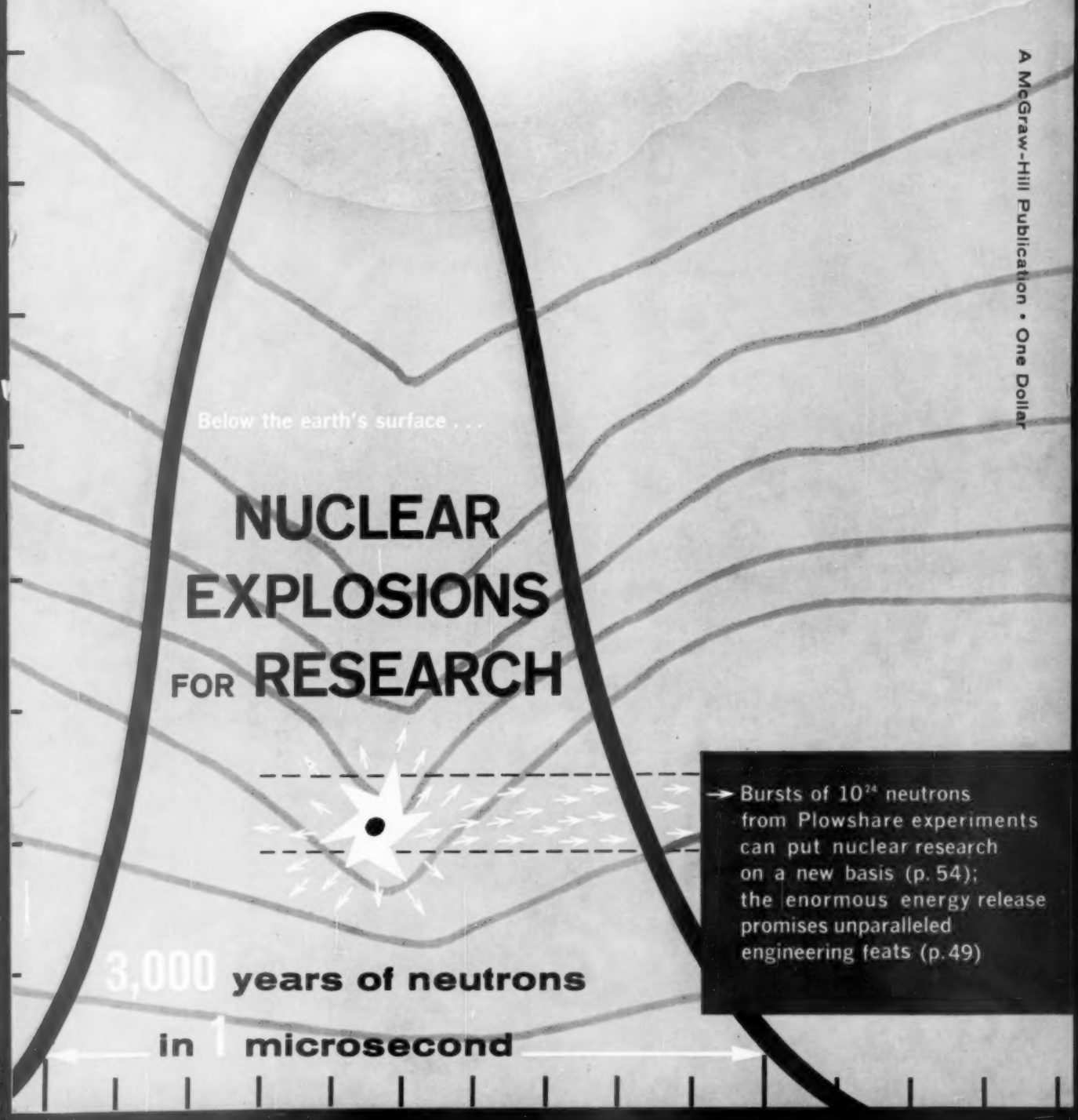

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JULY 1960

VOLUME 18 NUMBER 7

FEATURE ARTICLES

49 Peaceful Nuclear Explosions: Status and Promise
GERALD W. JOHNSON

54 Neutron Spectroscopy with Nuclear Explosions
DONALD J. HUGHES

59 Data Sheet No. 38—Criticality of MTR-Type Fuel Elements
ROBERT E. LIGHTLE

60 Reducing Radioactivity Buildup in PWR's
WILLIAM S. BROWN and CARL A. BERGMANN

64 Applied Radiation Case History No. 5—Radioactive Gages for Air-Cooled Turbine Blades

I. Liquid-Source Gage for Hollow Blades and Vanes
WILLIAM J. MAYER, WALTER H. LANGE and WILLIAM L. SHELLY

II. Scanning Beta Gage for Cooling-Channel Walls
HERBERT E. FARMER

INSTRUMENTATION & MEASUREMENTS

70 Transistor Amplifier for Fast Proportional Counting
JOHN B. S. WAUGH and ROY W. NICHOLSON

76 Xenon-Krypton Separation by Gas Chromatography
R. C. KOCH and G. L. GRANDY

NUCLEAR ENGINEERING

82 Selecting Instruments for Organic Reactors

84 Hydrogen as a Power Reactor Coolant
DOUGLAS BRADLEY

91 Safer Packages for Shipping Fuel
W. B. LEWIS and R. W. GOIN

APPLIED RADIATION

94 Gamma Gaging Solves Coal Flow Problems

96 Precise Tracer Measurements of Liquid and Gas Flows
COLIN G. CLAYTON

DEPARTMENTS

NUCLEAR REACTIONS	6	PRODUCTS AND MATERIALS	103
NEWS OF THE MONTH	21	INDUSTRY NOTES	110
APPLIED RADIATION	94	NEWSMAKERS	111
RUSSIAN NUCLEONICS	101	NUCLEAR CAMPUS	113
BOOKS	102	NUCLEAR CALENDAR	114

COMING FEATURES

NEXT MONTH

Comparative Value of Bred Fuels
Nuclear Power in Outer Space
Radiation Effects in PVC
New Electron Accelerators

LATER MONTHS

Radiation Effects Report
Beryllium for Reactor Application
Isotopes in Plant and Laboratory
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...about NUCLEONICS

The Other Half

A magazine, like the Roman god Janus, has two faces—an editorial face and an advertising aspect. We don't know what troubles Janus may have had in getting around, but this duality has only helped NUCLEONICS (and indeed all of the McGraw-Hill Publishing Company) which observes a strict separation between advertising and editorial interests.

But there is also a wholeness in our duality. For one thing most of our advertisers are also readers, and most of our readers, studies show, are interested in our advertising. And the men of our advertising sales staff are friends to us and many of you. To give you a chance to know them better we present below a picture taken at the time of our most recent sales meeting.

Plowshare

If there are to be advertising sales people or editors or even anybody ten years from now we have all got to find a way to prevent atomic war. The major atomic powers are seeking a formula for banning weapons tests as a step along the road to atomic disarmament. Agreement has been reached on techniques for detecting above ground violations of a possible test ban but underground tests below a certain size (and tests in outer space) may prove much harder to detect (see article by Carson Mark, NU, Aug. '59, p. 64).

Woven into this complex design is the question of possible peaceful uses of underground explosions. U. S. interest in this matter has been pursued under the title of Project Plowshare. We present in this issue a review of the Plowshare project by its leader (p. 49) and a stimulating discussion by the late Don Hughes of the great scientific potential in the enormous neutron fluxes available (p. 54). But further exploration of the technical potential in Plowshare depends heavily on the test ban climate. As you read our technical account we hope you will ponder the political issues that relate to it.

—The Editors

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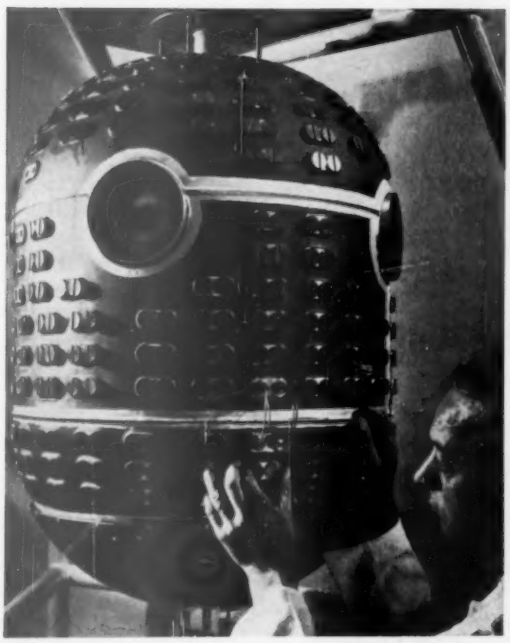
Isotopic Power for Space

Reliable, Compact Power Source Uses Thermoelectric Conversion



SNAP I-A, currently undergoing electrical test

Cutaway showing location of heat source

SNAP I-A—DESIGN DATA

Power Output	125 electrical watts for one year
Voltage	28 volts
Height	34 inches
Maximum Diameter	24 inches
Weight	175 pounds
Fuel	Cerium—144
Thermoelectric material	Lead telluride
Number thermoelectric pairs	277
Generator efficiency	5%
Watt hours/pound	6200 (1 year life)

Successful space exploration depends a great deal on lightweight, reliable and compact sources of electrical power for instrumentation and transmitters in space vehicles.

The Martin Company, as prime contractor to the U. S. Atomic Energy Commission, is developing a unique concept of power generation to fulfill this requirement.

The approach uses heat produced by decay of a contained radioisotope as the fundamental energy source. Heat is transformed directly into electricity without use of moving parts. Devices using this concept offer simplicity, ruggedness, and inherent dependability.

The period over which power is generated is determined by the half-life of the isotope selected. As much as several hundred watts of continuous electrical power can be generated, with operational lives extending to decades.

Martin has demonstrated feasibility of the concept in prototype devices and is already testing major components of systems suitable for operational use. One such system is SNAP I-A*, which has been designed to deliver 125 watts of electrical power for one year. It will be fueled with Cerium-144, a fission by-product.

Unlike solar energy conversion systems, the operation of SNAP I-A is independent of vehicle orientation or incident solar flux. Thus, it is ideally suited to missions in which the vehicle is eclipsed or must operate in dense atmospheres surrounding some planets.

Exhaustive tests and analyses, including exposure of the radioisotope capsule to fire, explosion and impact, have demonstrated that SNAP I-A can perform a space mission with complete safety.

While isotopic power holds great promise in space exploration, there are numerous land and sea-based applications which also require reliable, unattended sources of power. These, too, are under active development at Martin's nuclear facilities in Baltimore, Maryland.

**System for Nuclear Auxiliary Power*

MARTIN

At $00^h00^m01^s$ GMT, July 1, 1960 Martin logged its 590,304,000th mile of space flight

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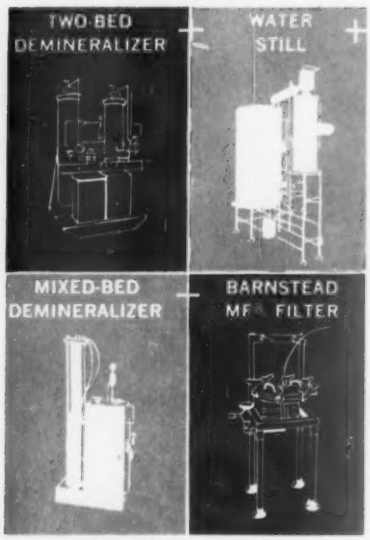

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NUCLEAR REACTIONS

Determining Enrichment

DEAR SIR:

I wish to comment on the article "U Enrichment Can Be Checked by Gamma-Ray Spectrometry" (NUCLEONICS, March, 1960, p. 107) by L. A. Sarkes and N. L. MacKinnon.

It should be pointed out that this is only true for pure uranium samples. Actually, the enrichment is not determined by gamma-ray spectrometry. Only the U^{235} content is determined, and the enrichment is calculated from the fact that the total U is already known.

The data in Table 1 for solid samples is very poor and should have been omitted. The percent deviation of the measured values from the NBS values, as I calculate them, are 0.55, 1.19, 3.53, 22.20, 18.25, 5.97 and 8.6.

The following table shows the type of data that can be obtained by carefully controlling the experimental conditions. The samples were 1-mil U foils. Only the 184-kev gamma from U^{235} was counted.

Mass Spec.	*Measured*	*% Deviation*
93.01 ± 0.05	Standard	
91.10 ± 0.07	91.4	0.33
81.2 ± 0.2	81.1	0.12
80.2 ± 0.2	80.9	0.87
79.2 ± 0.2	79.8	0.76
61.3 ± 0.4	61.6	0.49
60.2 ± 0.4	60.3	0.17
40.4 ± 0.4	40.5	0.25
39.6 ± 0.4	39.2	1.01
21.4 ± 0.2	21.4	
19.3 ± 0.2	19.4	0.52
For lower ranges, 19.3 was used as standard		
19.3 ± 0.2	Standard	
15.09 ± 0.15	15.4	2.05
10.1 ± 0.1	10.2	0.99
5.27 ± 0.05	5.4	2.47

—RONALD B. PERRY
Metallurgy Division
Argonne National Laboratory
Lemont, Illinois

DEAR SIR:

We appreciate the interest Mr. Perry has shown in our article, and we are happy to see that he is using the technique described with such good precision.

His criticism of the precision of solid-sample data is valid. These data were presented, however, to demonstrate the simplicity of making approximate enrichment determinations. This type of information is valuable to accountability personnel for sorting purposes. The samples were 1-gm NBS standards in powder form; we have also obtained good accuracy with uranium or uranium-alloy foil.

The liquid-sample data were presented to show the precision attainable with samples of more closely controlled geometry.

The isotopic analysis we briefly described in the article can yield accurate data, not only for pure uranium samples, but for samples of known uranium weight percent, provided, of course, that the other constituents are not radioactive.

—L. A. SARKES and N. L. MACKINNON
M & C Nuclear, Inc.
Attleboro, Massachusetts

Industry Plays Hooky

DEAR SIR:

Industry's relative inactivity in isotope applications, in my mind, is rather baffling.

American industry has always prided itself upon its willingness to accept and exploit new ideas and new techniques, yet industry as a whole has made use of radioisotopes to only a small extent—relative to what it could be doing. This is not true of all industries. For example, a great deal of interesting and useful work involving radioactive tracers has been carried out in the petroleum industry, and almost all of the major oil companies have active radiochemistry groups.

The relative apathy of industry as a whole, however, is shown in the enrollments in the ORINS radioisotope training courses. Over the years, the students in the basic 4-week course have been predominantly from the fields of biology and medicine, rather than from industry.

In 1959, a 6-week course was initiated, especially for industrial scientists and engineers. This course not only offers all of the basic training in radioactivity and radiochemistry included in the 4-week course, but also includes a comprehensive lecture and laboratory offering of radiochemical applications to all types of industry. Three such courses were given in 1959 with suitable attendance, but certainly no backlog,

and the response in 1960 is still rather feeble. This is in contrast to the response to the 4-week course, primarily for students in the biological and medical fields, which is booked up already for all of 1960 and into 1961. Both courses are now broken up into 2-week sections, allowing several combinations and increased flexibility.

I think that industry in general still labors under some mistaken notions of the hazards, costs and AEC red tape of investigations involving radioactive tracers. Actually, such work is one of the safest types of investigation, is a very powerful and versatile tool, and can be carried out quite extensively with a very modest investment in equipment and a minimum of red tape.

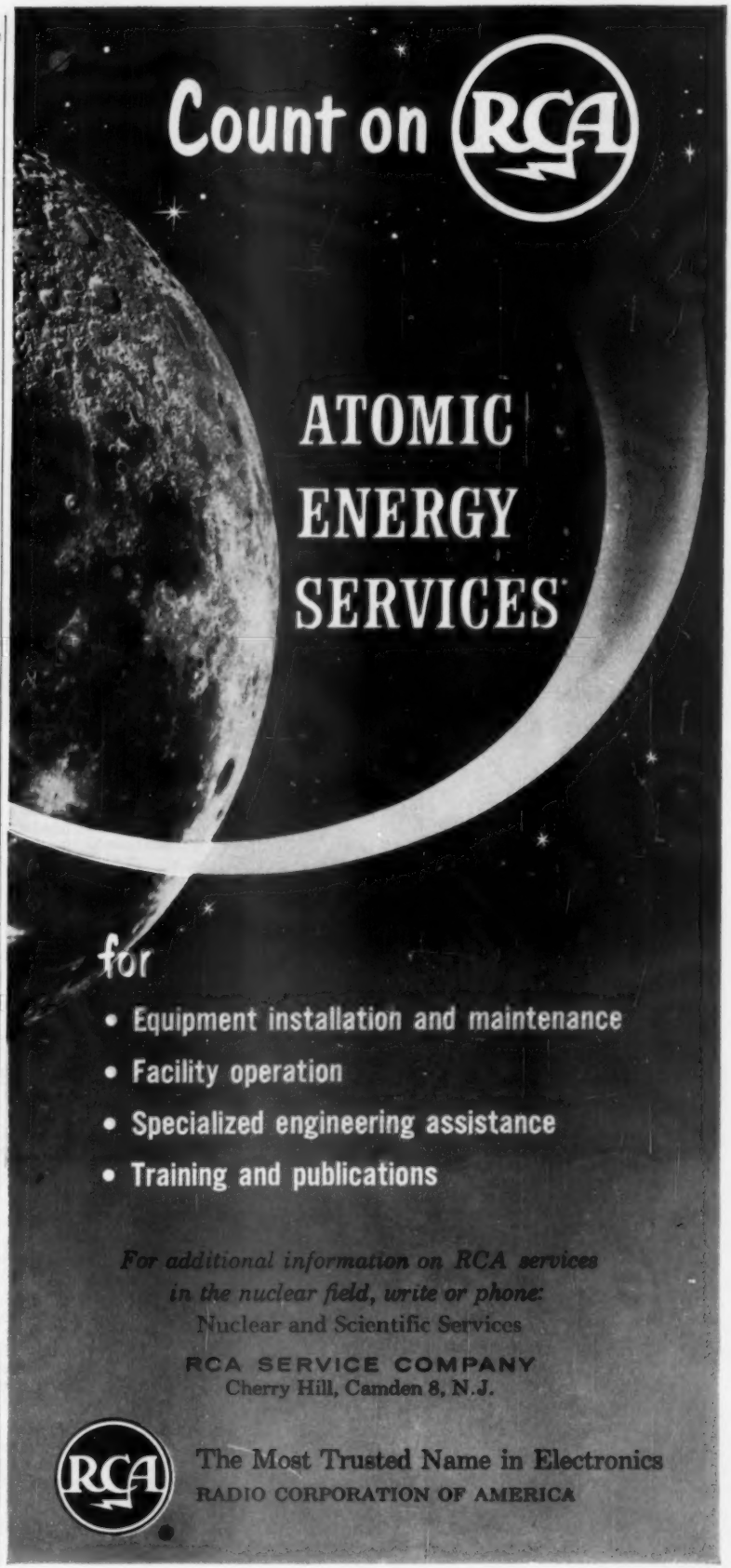
For example, one can do useful radiotracer work with an investment of as little as $1,000 in equipment and can equip a highly versatile radiochemical laboratory for as little as $10,000. These costs are certainly low compared with even single items such as mass spectrometers, infrared and ultraviolet spectrometers, X-ray diffraction cameras, emission spectrographs, electron microscopes, ultracentrifuges and X-ray fluorescence spectrometers—each of which costs as much or more than a completely equipped radiochemistry laboratory. Yet industry regularly buys quantities of such instruments with scarcely a second thought.

As I mentioned earlier, industry's apathy baffles me. Presumably time and understanding will gradually result in increased participation by industry.

The United States has had a head start over the rest of the world in the entire field of nuclear power, high-intensity radiation chemistry and radioisotope applications—due primarily to our early development of the nuclear reactor and concomitant development of advanced types of counting equipment. But this advantage is being lost by American industry, as one can see by even a cursory examination of the rapidly increasing literature in this field in Soviet journals.

VINCENT P. GUINN
Shell Development Company
Emeryville, California

EDITOR'S NOTE: The preceding letter was submitted to this department at the invitation of NUCLEONICS.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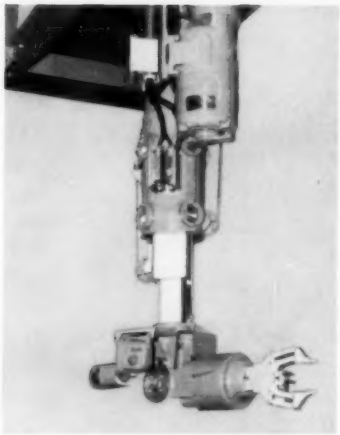

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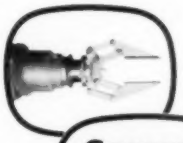
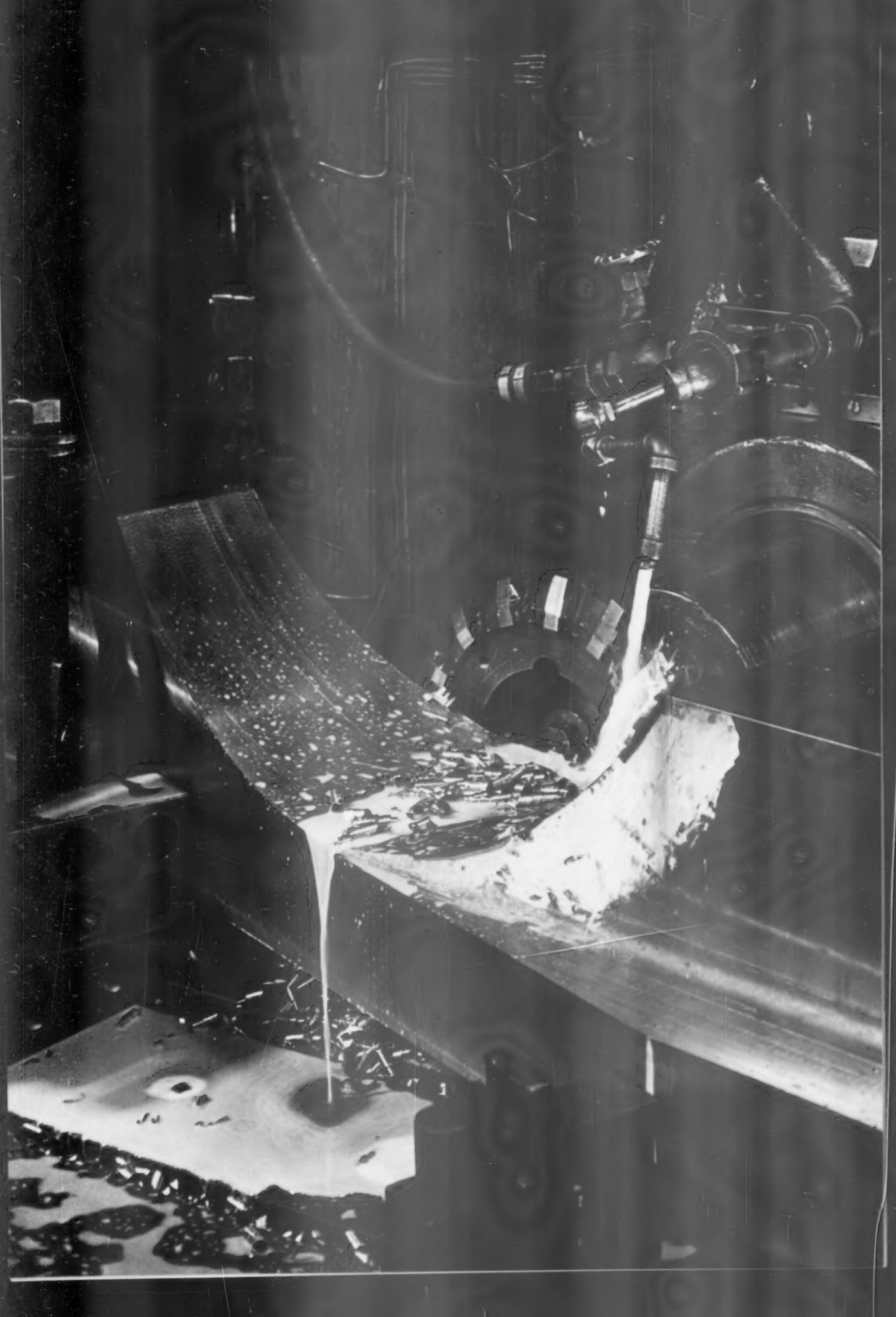


Nuclear Equipment Department

General Mills MECHANICAL ARMS



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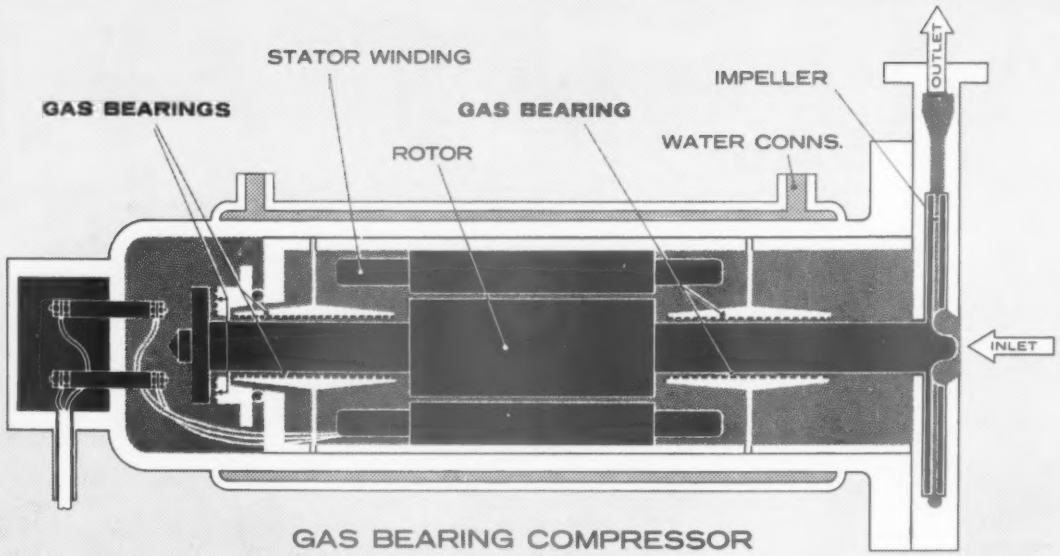

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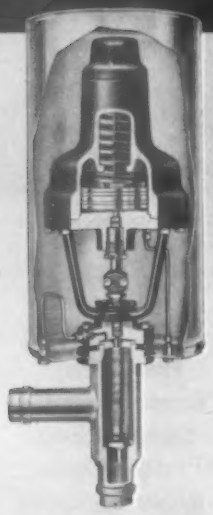

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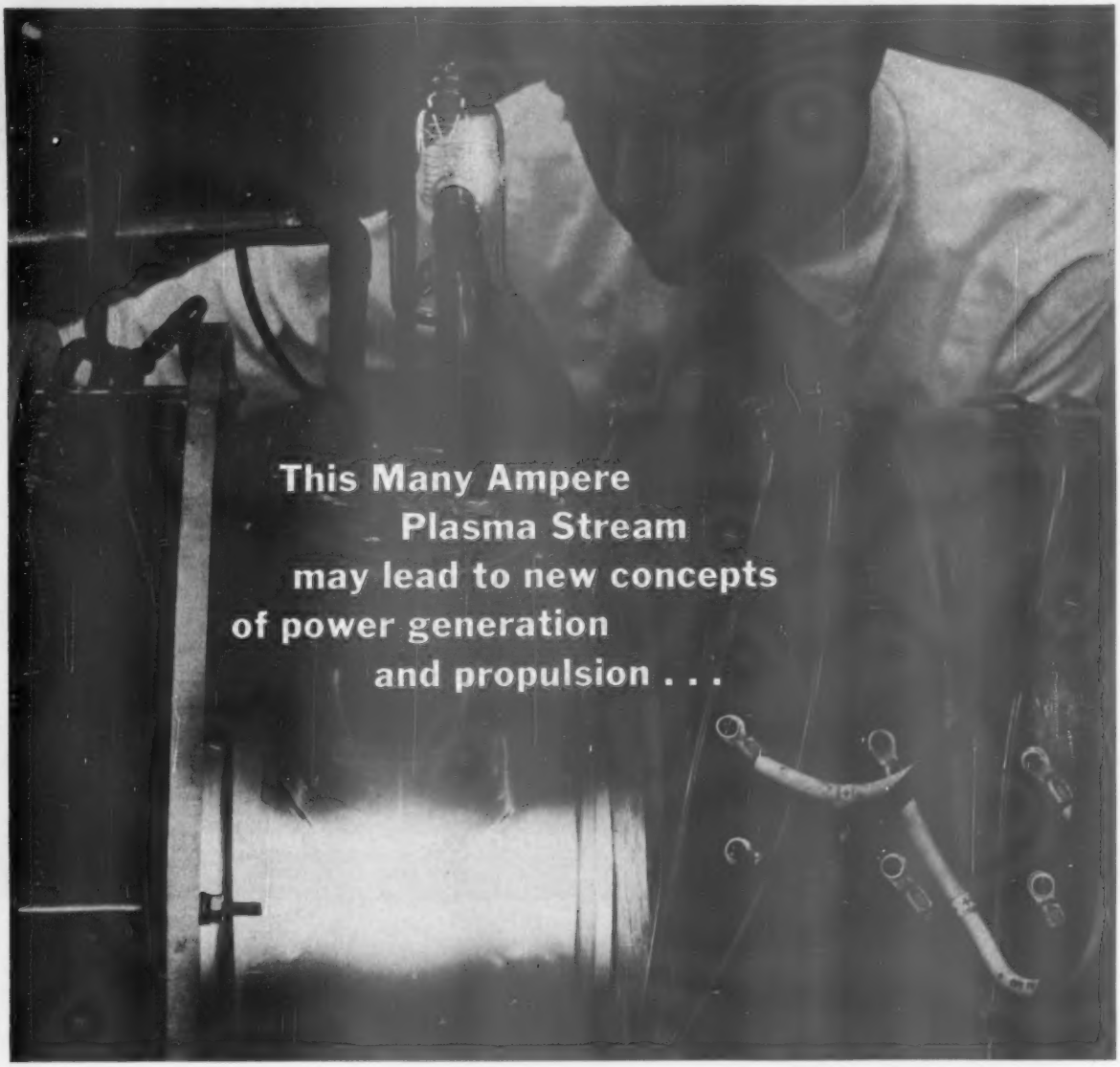

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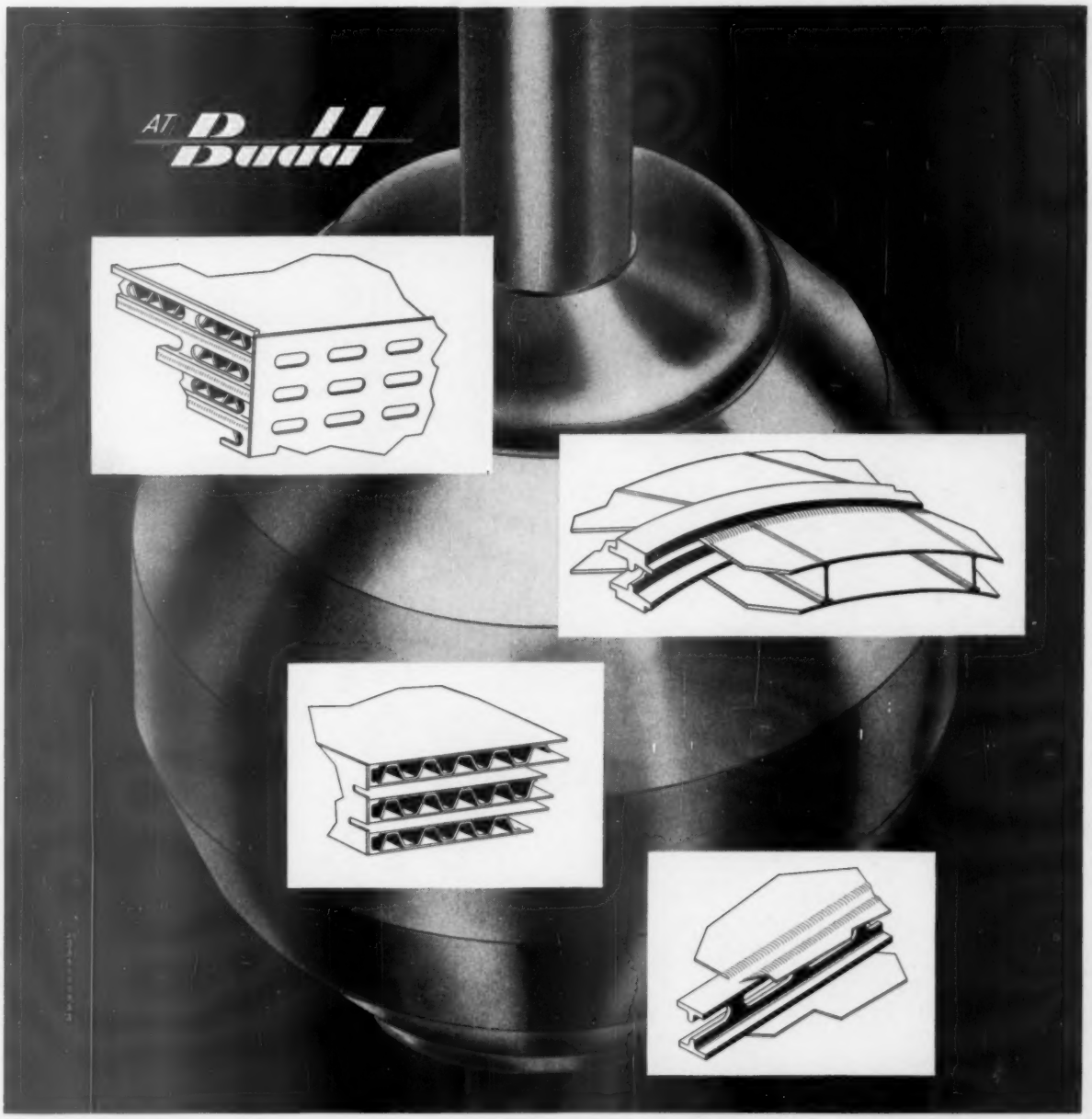

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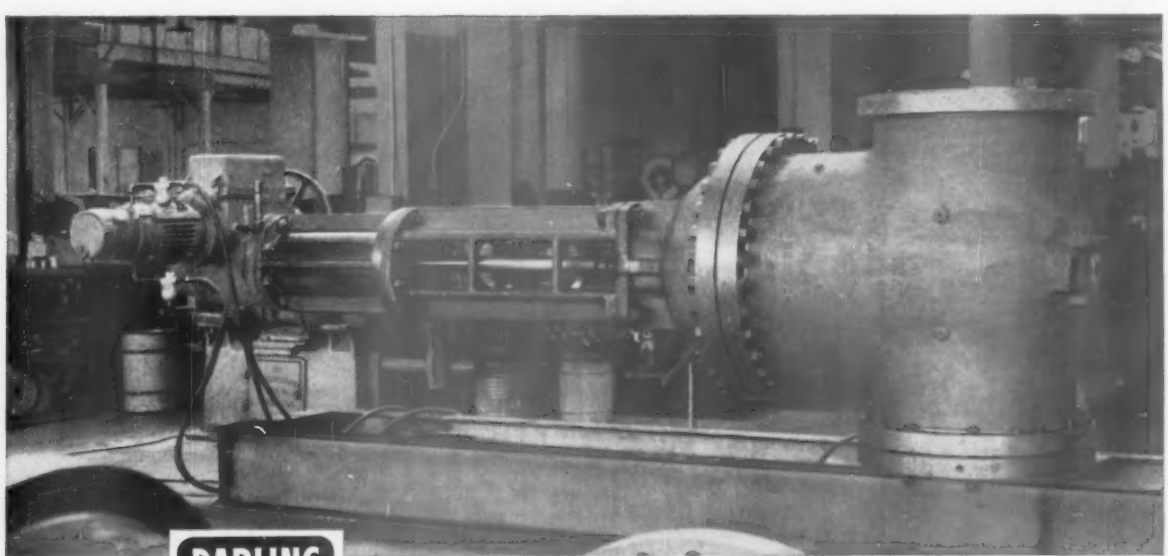

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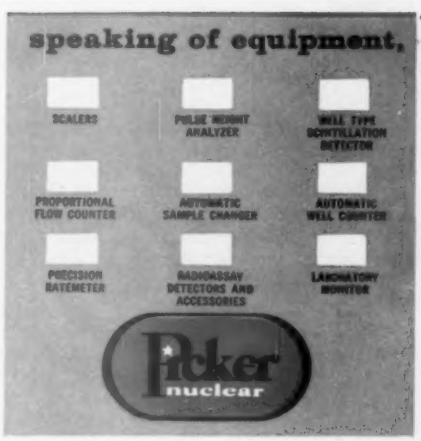

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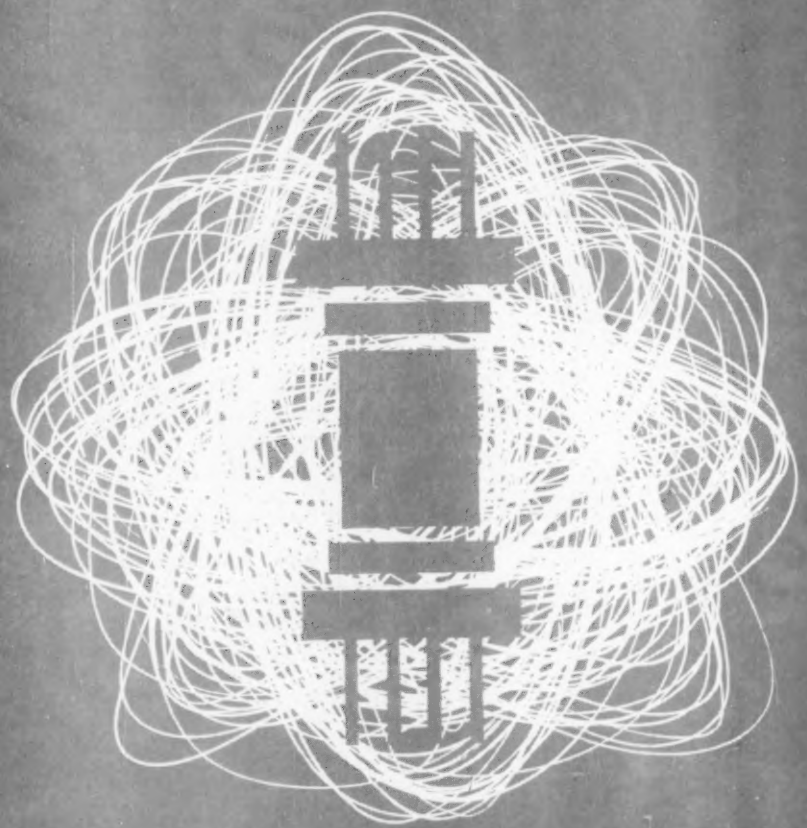

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NUCLEONICS NEWS OF THE MONTH

AEC Appeals as Circuit Court Voids Fermi Construction Permit

A blow from an unexpected quarter reached out to strike the U. S. nuclear power industry when the U. S. Court of Appeals for the District of Columbia Circuit, in a 2-to-1 decision last month, upset AEC's grant of a construction permit for the $88-million Enrico Fermi fast breeder reactor at Lagoona Beach, Mich., near Detroit.

The Commission decided, after a hastily-called meeting Monday morning, to ask the Solicitor General to request a rehearing before the full nine-man bench of the Circuit Court. Should this be denied appeal to the Supreme Court is likely.

The sweeping majority opinion, written by Judge Henry W. Edgerton and concurred in by Judge David L. Bazelon, said AEC's findings that the Fermi fast breeder reactor could be operated without undue risk to the health and safety of the public were inadequate. It went on to say not only that AEC may not issue provisional construction permits, but must make the same finding (that the particular reactor can be operated at the particular site proposed without risk to the public) that it makes when it grants operating licenses after construction is completed. It also said that even had AEC made such a finding, the court might not have accepted it. And then it went far beyond and held that AEC must show "compelling reason" for locating any power reactor near a large city.

In a vigorous dissent, Judge Warren E. Burger said he did not believe there was any occasion at this time for the court to pass on the issue of the ultimate safety of the plant's operation. And he scouted his colleagues' "erroneous opinion" that because millions of dollars had been invested in the plant, AEC would relax its standards and bail out the builders by issuing an operating license even though the plant's safety might be in doubt.

The United Auto Workers—one of the three labor unions that intervened to fight the construction permit when it was first issued in August 1956, and appealed to the Circuit Court when after years of hearings AEC confirmed its action in December 1958 and May 1959—declared that "the decision is a victory of those of us in this heavily populated area who have a deep respect for the power of the atom." PRDC's general manager Robert W. Hartwell said he felt it was ridiculous to require a state of design and experience equivalent to that required for an operating license before ground is broken on a nuclear project. Detroit Edison, who is building the turbogenerator plant and would use the 100-Mwe reactor's electricity on its network, is continuing its construction of the non-nuclear end on schedule, and feels confident "the construction permit will be reaffirmed . . ."

AEC Chairman McCone issued a statement pointing out that granting of the permit in 1956 and oral argument on it in 1956–58 took place prior to his joining AEC.

Spokesmen for JCAE said they did not expect any attempt to enact legislation on the matter during the brief remainder of this session of Congress.

The unsettling, dislocating effects of the court action—baleful, indeed, if they stand—fall into three categories:

1. PRDC. The action was against AEC. PRDC, already struggling with a serious fuel-element-design problem for its Fermi reactor (NU, March '60, 29), now also finds its goal at stake as result of the action. The court's mandate was not to come down for 15 days, or June 25. If the court accepts AEC's petition for a rehearing, the construction permit remains in effect until the full court acts. If the petition is denied, AEC can petition the Supreme Court for review—but the Supreme Court reviews only about one case in ten. If AEC is unsuccessful in obtaining further review, work on the nuclear portions of the plant at Lagoona Beach must cease. However the Fermi builders could continue work in the interim on installing the turbogenerator plant at the site, and on fuel design and fabrication problems off site.

2. Ten other holders of construction permits were inspecting their permits. About three or four contain unqualified final findings as to the suitability of the site, or as to both site suitability and the safety of the reactor. The others state merely that reactors of the general type concerned are safe; these permits all now have the shadow of the Circuit Court decision hanging over them.

3. AEC. AEC had felt that its approach to construction permits—granting of provisional permits based on reasonable assurance that by completion time the plant could be demonstrated to be safe—was both proper and legal. But AEC was most bitter about the new "compelling reason" test on site selection, which it feels the court "made up of whole cloth." Said one official, "We could live with the ultimate safety test. But we can't live with the compelling reason test for locating a reactor near a population center. You can't put a reactor within 30 miles of two million people; where do you draw the line? Under this we couldn't put a reactor anywhere but in the Idaho desert."

New reactors: Antarctica, barge plant, gas experiment

AEC last month invited fixed-price bids for a 1.5-Mwe pressurized- or boiling-water reactor at McMurdo Sound; the bid also asked options on one or two more 1.5-Mwe reactors for McMurdo, which options AEC or the Navy could take up by Aug. 15, 1961. Bids are due July 18 and contract award Aug. 1, subject to availability of funds (the Senate is expected to provide $13-million for Antarctic reactors but only McMurdo will go ahead now).

Other June reactor developments: The Army Engineers have asked bids in August for a 10-Mwe, non-propulsion, water reactor for installation in a Liberty-ship hull (only design funds available now). . . . AEC may schedule construction of a beryllium-moderated, gas-cooled maritime reactor experiment at Idaho.

House Appropriations Committee Launches ANP Inquiry

The Defense Subcommittee of the House Appropriations Committee begins this month an inquiry which its chairman says has as a major goal the narrowing of the Aircraft Nuclear Program (ANP) to one concept—with the indirect-cycle approach of Pratt & Whitney having the edge, at this point, over General Electric's direct-cycle approach.

The Congressional probe, to be led by Rep. George H. Mahon (D-Tex.), will be kicked off by a round of visits to installations doing ANP work. Simultaneously, the Mahon group's staff will get to work on material-gathering to lay the groundwork for hearings on the program during the next session of Congress.

Meanwhile, the Administration expected completion this month of the latest in a series of its own ANP studies—this one by an ad hoc subcommittee of the Air Force Scientific Advisory Board (SAB).

Mahon's inquiry was scheduled during this year's appropriations hearings on the AEC budget, when the ANP program came under severe attack by several members of the Appropriations Committee. They bristled at the $980-million expenditure consumed during the project's off-again, on-again 13-year history and were startled by the lack of tangible results. Consequently, the $73-million requested by AEC was very nearly axed by the Committee, when a narrow 19–18 vote barely saved the program but reduced funds to $58-million (NU, June '60, 21).

Rep. Melvin Price (D-Ill.), chairman of the JCAE subcommittee which has followed ANP longer and closer than any other Congressional body, supported the continuance of a broad, maximum effort developmental program. Price told NUCLEONICS: "It would be a horrible mistake—the height of folly—to cancel direct-cycle work. The direct cycle has actually developed the feasibility of nuclear flight, and with it we can put a plane in the air now."

Mahon, in disclosing details of the special study to NUCLEONICS, said that one thing which could "go a long way toward satisfying Committee critics" would be for the joint Defense Dept.-AEC program to settle on one or the other of two concepts being followed in developing a nuclear propulsion engine. Mahon's statement that the subcommittee was greatly impressed by progress made by Pratt & Whitney and Oak Ridge National Laboratory on an indirect cycle plant, in essence, bespoke the rapidly growing opinion on Capitol Hill that work by General Electric on direct cycle should be de-emphasized.

Air Force Ad Hoc Study

The 15-man SAB Ad Hoc group (including consulting aerodynamicists, nuclear materials specialist and physicists) is headed by E. H. Plessett, former Rand physicist, long an SAB member, and head of a consulting firm.

The Plessett survey began in June at Germantown with a management and background type briefing of the project from the AEC Aircraft Reactors staff. The group throughout the remainder of the month visited principal field test and developmental facilities involved in ANP work.

Principal reason for the Air Force study, explained Gen. Irving L. Branch, ANP chief, is to assess degree of technical progress made since the program was re-directed last summer. At that time, developmental efforts were re-oriented from fly-early-at-any-cost essentially to advanced research.

Mahon Writes to Eisenhower

Mahon said he was writing the President to call his attention to current "mismanagement" and to guarantee a top-level Administration look at ANP. "I want the people in charge of the program to face up to these problems more than anything else; so far after spending $980-million down through the years with no positive results, it seems nearly everyone connected with the program has to pay it lip service," Mahon said.

The subcommittee staff—with the assistance of outside consultants—will bend its efforts to completion of the study and constant surveillance of the program up to the next session of Congress, according to Mahon, at which time he will seek a showdown.

As for the possibility of Russia out-Sputniking the U. S. in ANP development, the House Appropriations Committee signified its leanings in the form of a mandate levied in its May report on the AEC budget:

"Should current reviews of the program find no appropriate military or peaceful application, then the entire ANP program should be abandoned as too expensive for the nation, notwithstanding the international prestige loss were Russia meanwhile to perfect an atomic plane."

Branch Welcomes Inquiry

General Branch defended the present program, including the work by General Electric on a direct cycle system, and stated that he was very glad the Congressional group is undertaking its separate study—"because they'll be looking at the same hard facts we do and in the end their conclusions will be the same as ours."

Steadfastly holding to the opinion that the program should continue following the two-concept development at the present $150-million per year level of spending aimed at flight in the mid-sixties, Branch said, "You can't go to supersonic flight with Pratt and Whitney until you learn something about the direct cycle; and if you get a nuclear plane into the air fast, there's no question but what you'll get it there with a direct cycle. . . . Fact is it's hard enough to work on this program, but as Rickover says, it's impossible to get anything done because of all the paper studies going on."

Another key Air Force administrator said in response to the insistence of the House Appropriations Committee that the nuclear aircraft have a definite military requirement:

"If we find it has no possibility of flight, or is of no more use than studying the sex life of a butterfly, then we'll cancel it. But it's very difficult for me to envision now specific applications—there were none hanging over the heads of the Wright brothers, you know. And it's also hard to envision anybody closing their eyes to a new field of propulsion."

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AGR Advances May Permit Non-Remote Reactor Siting

Britain is thinking about a new horizon for its AGR (Advanced Gas-cooled Reactor): location in densely-built-up industrial areas. This would result if total containment of commercial-size power reactors of this type becomes economically feasible, as now seems possible thanks to reductions in volume that flow from novel features adopted for the first time in the engineering structure of the prototype AGR nearing completion at Windscale.

This was one of several points advanced to NUCLEONICS by Sir William Cook, member for engineering and production of the U. K. Atomic Energy Authority, in a new statement of confidence in the AGR concept. This is the second of three stages in British development of gas-cooled reactors. (The first is Calder Hall and its successors: Bradwell, Berkeley, Hunterston, Hinkley Point, Trawsfynydd, under construction, and Dungeness and Sizewell, soon to be started; the second is AGR, also graphite moderated and CO_2-cooled but using slightly-enriched uranium and—eventually at least—beryllium cladding instead of magnox; the third is HTGC (High Temperature Gas Cooled), using graphite-clad ceramic fuel. AGR is represented in hardware by a 28-Mwe prototype (NU, Jan. '60, 23) under construction on schedule at Windscale with completion set for April 1961. HTGC has had a critical experiment, Zenith, completed at Winfrith Heath, and a 10-Mw pilot plant, Dragon, recently begun at the same site.)

The first commercial-size AGR is expected to be 500–600-Mwe. The belief is it will be located alongside a Calder-type station at the Oldbury-on-Severn site (NU, March '60, 26). Sir William and the Central Electricity Generating Board still decline to give a firm date for start of construction on the pioneer large AGR, but Sir William indicated work was not likely to start for another two years on such a unit.

Clearly the main obstacle in exploitation of the AGR system is not nearness of any rival reactor concept, but simply the need still to resolve questions concerning behavior under irradiation of beryllium and stainless steel, competing for the fuel-cladding role. But the metallurgical snags involved here are still thought by top UKAEA reactor personnel to be trivial compared with the latent nastiness that might well assert itself in the development of the HTGC.

It was made abundantly clear that the time scale now envisaged in the development of AGR and HTGC systems respectively leaves an ample period for exploitation commercially of the AGR.

AGR Economics

Power cost in an early AGR system at the reactor size contemplated should be close to 0.5 pence/kwh (5.8 mills), said Sir William, and hence equal to the best of any coal-fired station available on the same time scale. The uncertainty about cladding would hardly reflect on the cost per kwh, the price differential being less than 0.02 pence.

From other sources, NUCLEONICS gathers that the cost/kw installed of a 500–600-Mwe AGR station, originally thought to lie in the region of $196–224, now looks to be as low as $168, on the basis of very recent optimization studies that have only just become possible within the digital computer capacity of the AEA.

Size-Reduction Potential

Compact geometrical configuration of the AGR prototype, which represents radical gains over Calder-type layouts, has been achieved by three new features:

1. The base of the heat exchangers is coplanar with the top of the pressure vessel. The support plane passes through the axes of the gas ducting, greatly simplifying the duct design. Also, the reactor vessel is suspended from points near its top dome to the external concrete shielding, utilizing for the first time the massive concrete walls for structural purposes.

2. Concentric inlet and outlet gas ducting between reactor and heat exchanger. This re-entrant gas-flow principle results in the economizer, the coldest region, being at the upper end of the heat exchanger with consequent advantage to the natural circulation of the coolant in the event of failure of the main circulators.

3. Introduction of an internal neutron shield above the core within the reactor vessel. This reduces the thickness of the biological shield above the reactor and prevents neutron streaming through the ducts, which consequently do not need to be right-angled or shielded. The arrangement also enables access on shutdown to the outside of the upper shell and its supports for inspection and maintenance, as well as controlled access to the inside of the reactor above the core after fuel discharge. It also offers the possibility of complete core replacement.

Another feature of the reactor is the separate access provided to each fuel channel. This is claimed to simplify the mechanics of refueling and discharging under pressure, and facilitates instrumentation of the fuel elements. The 400-ton refuelling machine, 60 ft high, can align itself automatically with any fuel channel to within 0.005 in.

AGR AT WINDSCALE NEARS COMPLETION. Compare photo NU, Jan. '60, 23. It is scheduled to go critical next April

Containment Philosophy

The promise of major size reduction holds out the possibility of using a total containment envelope around the reactor, something that neither Calder Hall nor any of its successor plants in Britain now have—they are simply too big. (Only the 15-Mwe Dounreay fast breeder pilot plant among British power reactors has a containment sphere.)

Space Looms as Major Market for Nucleonics Industry

Nucleonics-in-space appears likely, long before this decade is out, to take its place alongside nucleonics-in-the-Navy as a major outlet for the reactors, isotopic-power sources, radiation instrumentation and related equipment produced by the nucleonics industry. Moreover, the outer-space applications of nucleonics, though coming along on a later schedule than the Naval program, appear likely eventually to surpass even it—in both size and breadth.

Isotopic power appears to be on the verge of acceptance (*see page 26*); radiation instruments have been in use for some time in both satellites and space probes; and the development of reactors for both propulsion and auxiliary power is being recognized as indispensable to interplanetary space exploration.

Aside from radiation instrumentation, an important nucleonics space market is only now beginning to develop. But developments in space radiation in recent months indicate the snowballing interest on the part of the "customer"—i.e., the federal government. Last month's developments:

RADIATION SAFETY

• **AEC policy.** AEC, which has responsibility for the safe operation of radiation devices in space, held a classified meeting June 2–4 preliminary to reaching policy decisions on when—and under what circumstances—nuclides and reactors may be employed. General Manager Alvin M. Luedecke and the AEC's Aerospace Nuclear Safety Board heard reports from the industrial contractors working on space applications, as well as officials of the National Aeronautics and Space Administration and other prospective users of nuclear devices. Luedecke's recommendations on AEC safety policy were then to go to the Commission.

• **Three-agency review.** Also considered at the AEC meeting was a recently completed, classified review of radiation-safety by staffers of AEC, NASA and the Defense dept. Authoritative sources said the report found no irreconciliable bar to the outer-space use of radiation devices. The report also specifically cleared Vandenberg Air Force Base—under certain safety criteria—for the firing of rockets carrying SNAP-3 devices for auxiliary power. Each of the three agencies participating in the report was reviewing it at top level and an unclassified summary of its conclusions is to be presented at a rocket conference in Santa Monica, Calif., Sept. 27–30.

ROCKET PROPULSION

• **NASA flight-test program.** An estimated 10–15 proposals were received by NASA May 31 for two $100,000 contracts on a flight-test program for the first nuclear rocket. Industry observers were expecting the contract awards early this month. Essentially, the contractors will suggest what a second- or third-stage nuclear rocket might look like (based on Project Rover technology) and how to meet the problems of launching and firing such a rocket in boosting it into space with a Saturn rocket.

• **Navy program.** The Navy disclosed that its Pt. Mugu, Calif., missile center was conducting a study "to investigate problems associated with the launch, test and recovery operations which Pt. Mugu may encounter in the research, development, evaluation and test of nuclear systems." Industry sources said Pt. Mugu was expecting proposals about mid-June for one or more contracts to evaluate current rocket technology in terms of the Navy's military responsibilities.

• **Air Force program.** NUCLEONICS learned the names of several of the winners of two funded and five nonfunded contracts from Edwards Air Force Base similar to those expected to be awarded by Pt. Mugu (NU, May '60, 24). Selected for funded contracts were Aerojet-General and the group Reaction Motors div. of Thiokol Chemical, Allison div. of General Motors, Linde div. of Union Carbide and Nuclear Development Corp. of America. Westinghouse and Martin won nonfunded contracts which, though carrying no financial support, give their holders access to classified rocket technology and also keep their ideas before the AF. Edwards was expected to make a formal announcement of all the winning contractors before end-June.

• **The 300-kwe SNAP reactor.** The AF's Air Research and Development Command at Wright Field, Dayton, Ohio, selected AiResearch Manufacturing Co. of Phoenix, a division of Garrett Corp., as prime contractor for development of the largest space reactor yet scheduled—800 kwe. AiResearch, which will supply the power-conversion machinery and engineer the complete package, selected Aerojet-General to supply the reactor.

The other finalists, reportedly, were Thompson-Ramo-Wooldridge and Sundstrand Corp., with all three finalists choosing the Aerojet reactor in preference to one offered by Atomics International, it was understood. Wright Field was placing development emphasis on the complete power system and did not want to commit development money to the reactor. So Aerojet was understood to have gotten the nod because it offered a simple scale-up of the zirconium hydride-moderated, sodium-cooled reactor developed by AI for SNAP-2 (3 kwe) and SNAP-8 (30–60 kwe), while AI proposed a more advanced version.

ISOTOPIC POWER

• **Martin Program.** Martin Co. is doing conceptual-design studies on isotopic-power sources for deep space probes and lunar-impact missions. In the latter category, it has completed conceptual design of a 13-watt device which would withstand impact and provide power for up to 13 months. Candidate radionuclides for such a device are polonium-210 and curium-242 (*see page 31*), since their half-lives of less than six months would mean a short decay period in the event of a mishap on impact.

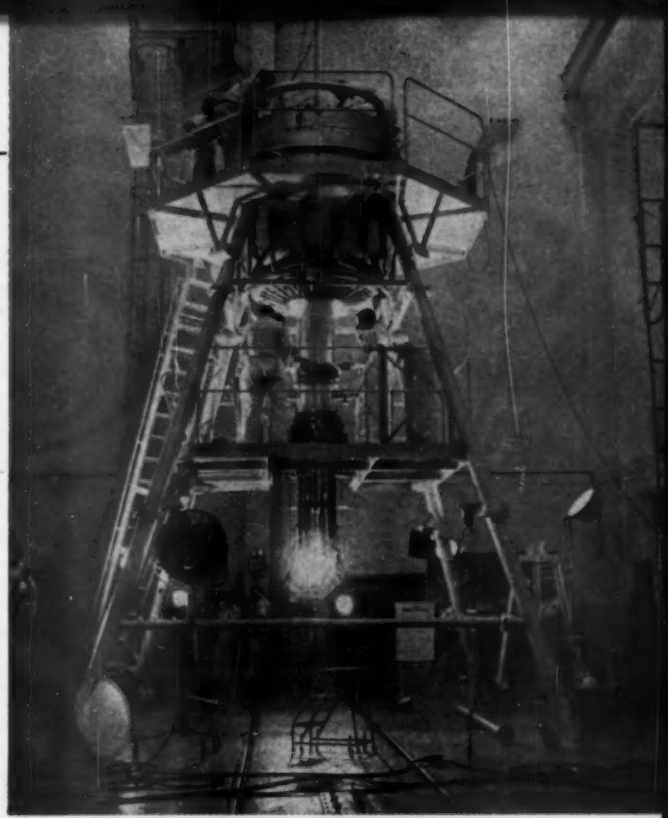
Martin representatives have also been visiting Quehanna, Pa., where Curtiss-Wright will shut down its 1-Mw pool reactor. Martin's interest is in the five adjoining hot cells, for possible use as a manufacturing plant for stronium-90 cores for isotopic power batteries. Martin had previously been denied permission to build an Sr^{90} plant at Middle River near Baltimore. The Navy reportedly wants Sr^{90} batteries for use as submarine navigating beacons.

RADIATION INSTRUMENTATION

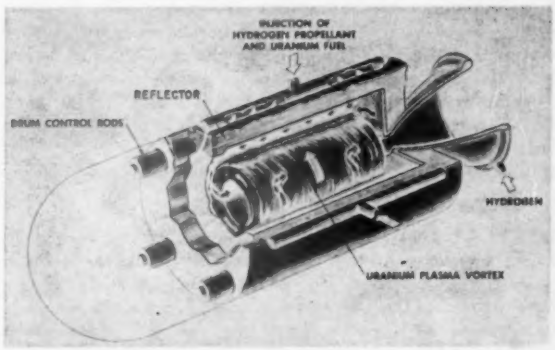
• **NASA meeting.** NASA, which is coming to rely more and more on the radiation-instrument industry for both satellite and probe equipment, has called a meeting for late July in Washington to brief these and other instrument makers on what the agency will need in the way of new instrumentation over the next ten years; some 1,500 scientific and industry people are expected to attend. Radiation equipment is a substantial portion of NASA's fiscal '61 budget of $80-million for satellite and sounding-rocket instrumentation.

Hardware—and Dreams: Atoms-in-Space Booming

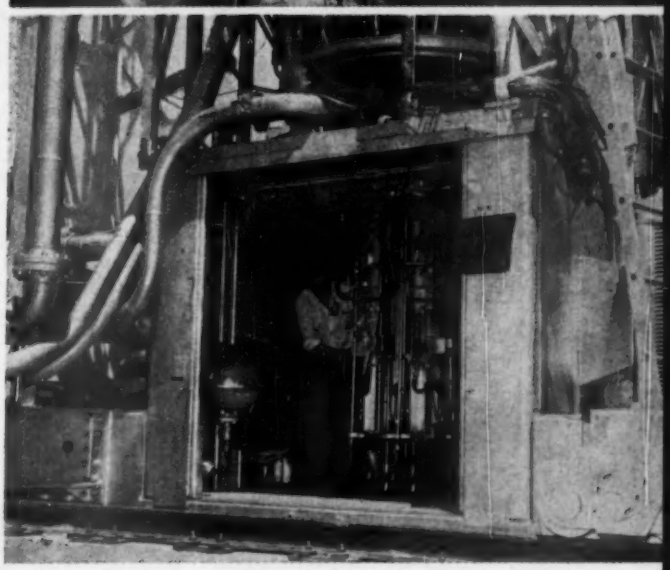
NUCLEONICS pictures here three aspects of the boom in applying nuclear energy for use in exploring space: work on actual hardware, represented by the second reactor in the Rover program, Kiwi-A-Prime (at right), now being readied for criticality this summer at the Jackass Flats, Nev., test site; a blue-sky advanced idea for a space propulsion reactor (below, center); and SNAP-10, an auxiliary-power reactor using thermoelectric power conversion, now being worked on at Atomics International.

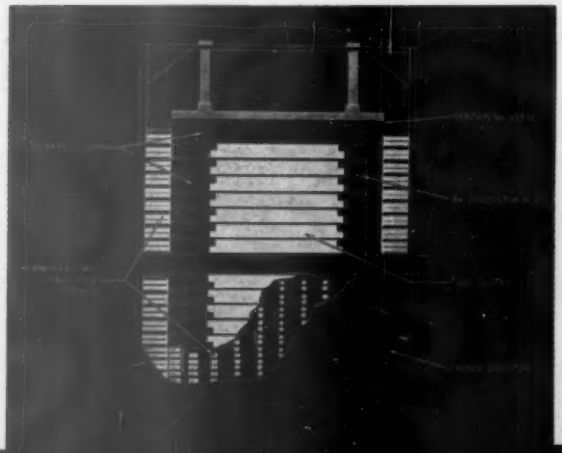


AT RIGHT: ACTUAL KIWI-A-PRIME engine is shown (at top) on test stand in MAD building (Maintenance, Assembly and Disassembly). Hanging below, down to corona effect from spotlights, is complex control-rod mechanism. (Right center) Control-rod mechanism of cold-flow mockup for Kiwi-A-Prime, mounted on railroad car on which it is moved into place by remote-controlled engine. ▶

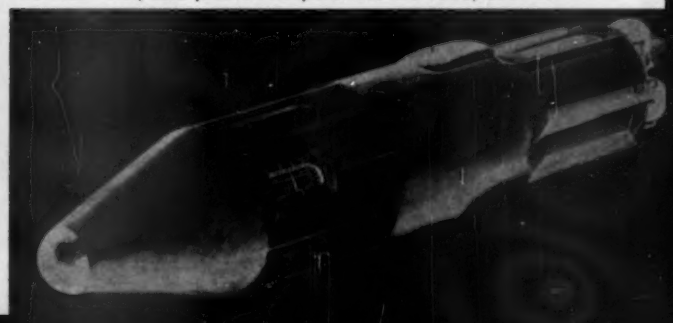


ABOVE: GASEOUS VORTEX REACTOR scheme could theoretically achieve temperatures of 90,000–100,000° F with hydrogen coolant, for a 4000-sec specific impulse. Finely-divided uranium fuel intimately mixed with coolant would provide high heat-transfer-surface area, would be kept in cavity by centrifugal force while lighter hydrogen is expelled through nozzle. Reflector would be graphite or beryllium. Sketch is by Douglas Aircraft Co. Brookhaven, Cal Tech are working along similar lines. Feasibility of concept is not yet proved. ▲

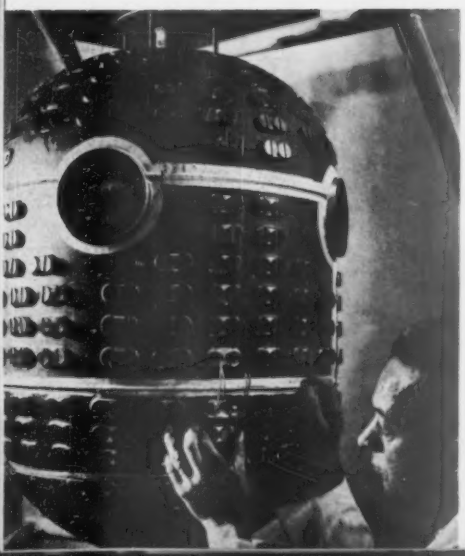




BELOW: SNAP-10 is a reactor using thermoelectric direct conversion. A peel-off of SNAP-2 technology, it uses the same advanced materials, physics and control techniques, but has only 1/10th SNAP-2's power output, or about 300 watts. Reactor power is 15 kw, system efficiency 2%, system weight 330 lb. Hot, cold junction temperatures are 1200, 800° F.



Isotopic Power Ready for Space But Caution Delays Use



In at least one aspect of the nation's space effort the state of the art is well ahead of the application—the use of radioisotopic auxiliary power sources. The U. S. now has capability to place in artificial earth satellites and space-probe vehicles SNAP-3 devices for powering sensory and communications systems. But the devices are not being exploited for reasons primarily psychological and political.

There are two major questions about isotopic devices—neither involving the question: will they work? They are: **1.** can they be managed safely from launch pad through all possible rocket aborts?; and **2.** is the U. S. opening itself to foreign criticism—particularly from the Soviets—in sending radioactive materials into outer space? In answer to the first question AEC officials say that SNAP-3, the 3½-5-watt polonium device developed by AEC and Martin Co., has been fully tested and could be scheduled immediately for launchings over the South Pole from Vandenberg Air Force Base, Calif.—although none is scheduled as yet.

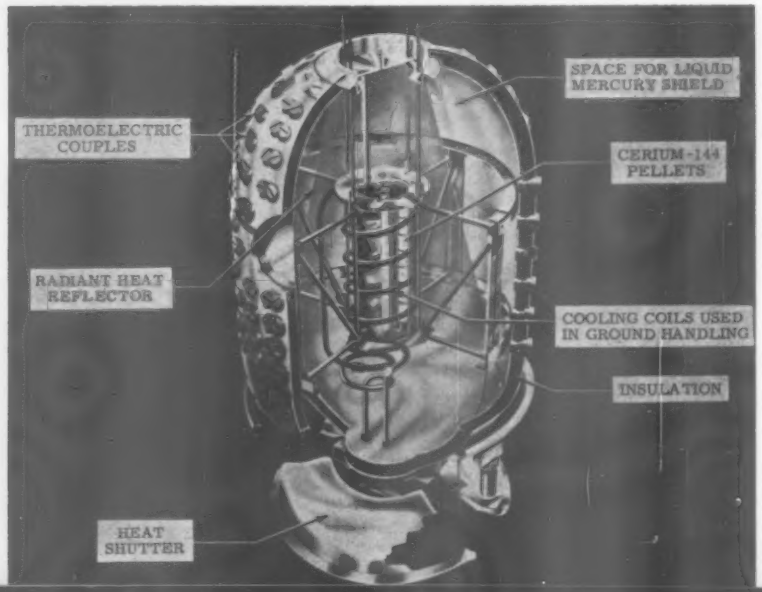
As for the international political problem—a particularly difficult one in view of the long controversy over weapons fallout—AEC tests to date show that it would take 100 years to come within two magnitudes of background radiation in the atmosphere (1/100th of background) if one SNAP-1A device per month were burned up on re-entry. (SNAP-1A is being developed to produce 125 watts with 880,000 curies of cerium-144 (*see photos*).

Parallels Antarctic Reactor Lag

The current isotopic-power impasse parallels in many respects the delay in utilizing nuclear power in the Antarctic (*page 21*). In both cases the nuclear technology has been successfully developed and the nuclear equipment is universally accepted as a good thing both economically and logistically. However, use of reactors in the Antarctic is hampered by artificial budgetary considerations (NU, Apr. '60, 27) and the use of isotopic power in space is hampered by the reluctance of rocketeers to accept radioactive devices on the launching pad and by the ever-present threat of international criticism.

These psychological and political

AN ARTIST'S CONCEPTION OF SNAP-1A in space, top left, shows two of the 125-watt devices feeding electricity to the instruments of a Discoverer reconnaissance satellite. Middle, first prototype of SNAP-1A and, lower left, second prototype, now under test at Martin Co. SNAP-1A is scheduled for first fuel loading in January, to be followed by a year's operational testing. Specifications: 125 watts at 28 volts; efficiency 5%, or 6,200 watt hrs/lb; 800,000 curies cerium-144 deliver heat at 277 pairs lead telluride thermocouples (see bottom cutaway); lifetime, 1 yr; size, 34 in. high x 24 in. max dia. To maintain 125-watt power, helium under pressure in dome is used as excess-heat conductor, leaking at constantly slower rate.



problems have loomed so large in the isotopic power picture that one AEC official despaired: "We have resigned ourselves to the fact that we'll use these only in missions where nothing else is available. However, our case is being helped day-by-day by failures in the other [competing] devices."

The alternative to isotopic power is solar power (the more powerful nuclear systems using reactors are expected to have little competition when they are ready). Though solar devices have been used with less than complete success, they present no pre-launch handling problems and the two agencies involved most deeply in rocketry—the Air Force and the National Aeronautics and Space Administration—continue to prefer them to radioactive devices.

But, while solar units have been able to produce small amounts of power for relatively long periods, they are impractical in missions calling for ruggedness (lunar impact, for example) and through areas devoid of sunlight (Venus is blanketed in light-blocking gases and the moon is dark on one side). Moreover, solar devices have a poor reliability record and, since in space missions the instrument package is all-important, auxiliary power failure is disastrous. "Dead pounds of satellite in orbit are not worth a damn," an AEC official pointed out.

Safety Program

Martin Co., prime contractor to AEC's Aircraft Reactors Branch for isotopic-power development, took SNAP-3—and is now taking SNAP-1A—through a test program anticipating every conceivable abort situation. The devices are being designed so they will remain sealed in any abort prior to leaving the earth's atmosphere but, at the same time, will disintegrate to molecular-size particles on re-entry. Particles of less than 10 microns, it is felt, will reside in space until long after the contained radioactivity has decayed to meaningless levels. The test program currently under way for SNAP-1A follows:

1. Pre-launch. Anticipating the possibility of the cerium core of a SNAP device dropping off of a rocket, the inconel-clad core has been preheated to its operating temperatures of ~2,000° F and dropped 70–90 ft to a concrete pad. The cores have been dropped into liquid oxygen (LOX) and scale models of an entire Atlas system with a cerium device have been dropped into exploding LOX and kerosene to simulate a pad explosion. In such an abort simulation the cerium has withstood temperatures of many thousands of degrees Fahrenheit and pressures of several hundred psi.

Isotopic vs. Solar Power

When will isotopic-power devices be put to use? An official of the Defense dept.'s Advanced Research Projects Agency put it this way: Solar devices are preferred over isotopic power because they present no radiation problem. However, recent solar failures, due to leaking of the storage batteries with which they must be used, is forcing consideration of isotopic power. Meanwhile, however, the battery industry is proceeding with a vigorous effort over the next year to perfect solar-cell batteries able to stand up in space. If isotopic power is actually put to use in the interim it may be here to stay, particularly for missions where there is no sunlight.

2. Recovery on re-entry. For the foreseeable future no device is likely to be built for recovery from outer-space. However, operating on the possibility that this may some day be desirable, Martin is testing molybenum-clad cores for ability to withstand re-entry shock. This includes subjecting the cores to rocket-sled impacts against concrete, granite and water barriers; in all cases the cores have remained intact with only slight plastic deformation. To simulate re-entry environment, the core is coated with an ablative and tested in a plasma-arc furnace at 8–9,000° F in the presence of re-entry gases.

3. Burnup on re-entry. The one admitted "gray area" in the entire radiation-safety program—as regards the safety of earthlings—lies in the possibility that a rocket may fall just short of necessary orbital speed; somewhere between 23,000 and 24,000 ft/sec there is a band of 100 ft/sec where, although the isotopic devices will surely burn up, the particles may be too large to remain above the atmosphere. However, AEC officials feel there would have to be thousands of such aborts to even approach the decay rate now existing in the atmosphere from weapons tests. Current tests show that in all other re-entry situations isotopic materials will disintegrate to particles no larger than 10 microns—a mass so small that residence time in space would go well beyond decay period.

4. Generator strength. In addition to the precautions being taken with the core, the generator, which carries the core and converts the heat to electricity, is being tested to withstand several types of shock, including launch stresses and the strain of jolts as much as 50 times gravity as the various rocket stages separate.

In short, AEC and Martin feel they have demonstrated for SNAP-3—and by the end of this year will have done the same for SNAP-1A—that every conceivable test that can be conducted on the ground has been carried out successfully. "We feel pretty secure," an AEC safety expert summed up, "about the safety of a SNAP-3 device in a polar orbit."

However, looking beyond SNAP-3, whose 5-watt capability is only a fraction of the power eventually expected from nuclear devices, AEC will go into an extraterrestrial test program later this year. The program, which is geared primarily to gathering conclusive evidence on what happens on re-entry of a radioactive device (verifying theoretical evidence), will involve rocket firings into the upper atmosphere from such sites as White Sands Proving Ground, N. M., and Wallops Island, Va. The rockets will be instrumented to send back data on air mixing rates, particle-settling rates and similar data. The tests have been scheduled primarily "to satisfy the political environment" in which radioactivity vis-a-vis the atmosphere is particularly sensitive.

First Shots from Vandenberg?

On the basis of a radiation-in-space safety study completed in May by experts at NASA, AEC and the Defense dept., it appears likely that the first isotopic generator will be used in a rocket fired from Vandenberg. This West Coast base is favored over Cape Canaveral, Florida, because a wide area south of Vandenberg to the South Pole has no large land mass; the South Polar route would take the rocket up over the Indian Ocean from Antarctica, across Madagascar (10,000-plus mi out of Vandenberg) and then across the Near East and Russia on its way to the North Pole.

If the rocket shows signs of straying early in its flight, it can be destroyed by the range safety officer; any abort down range might be handled by picket ships; then, beyond the opportunity for destroying the missile, it is felt that an abort below re-entry speeds would drop the SNAP generator either in Antarctic wastes or in ocean water; just before reaching a Madagascar latitude the rocket would either be in orbit or on its way to outer-space or re-entering the atmosphere at burn-up speeds.

REACTOR NEWS

WTR AFTERMATH: MANY LESSONS LEARNED

Only one element failed in the Westinghouse Test Reactor early in April (NU, May '60, 27). Although the fragments of the failed element were mangled upon removal so that hot-cell examination could not yield maximum results, it is now believed the element had an area at least half an inch square on one tube segment where meat and cladding were not properly bonded, and that a hot spot developed here, swelled and shut off coolant flow. Among lessons already learned from this incident:

- **More thorough examination** of delivered fuel elements by the reactor operator can prevent accidents, might have prevented this one.
- **Value of the blister test,** long a standard tool, may be in serious question for tubular alloy elements. The element segments had been blister-tested at 900° F, but *before* being rolled into longitudinal segments of cylinders (to form tubes).
- **A reactor's on-site waste disposal plant** should no longer be regarded as a necessary evil, first to be cut back if funds get tight. What to do with low-activity waste water used in cleanup operations has emerged as a major problem in reactor management: Westinghouse has had to have some 36-odd 20,000-gal holdup tanks erected on the WTR site (at about $3,000 each, total cost is over $100,000), and is now adding a 500,000-gal tank. It has concluded its original evaporator (capacity ½-gpm) is "frankly a toy, okay routinely, no good at all in such an emergency"; but a larger one to be installed won't be operational until August. Indeed,
- **. . . insurance circles** are beginning to think of penalizing insured reactors—where it hurts, in the premium—for inadequate holdup water capacity.
- **Unrealistic regulations** are also spotlighted: waste water disposal was not facilitated by state law requiring water dumped to streams to contain no more than 10^{-4} millicuries/cc activity. Rainwater has averaged 10^{-7} in the area.
- **Personnel exposure-time** is another cleaning-up headache. Everyone who would volunteer was pressed into service to remove shroud tubes in the subpile room, one of the hotter areas (local field above 50-r/hr around the bolts, six of which fastened each shroud tube). Maximum exposure time per man was 2½ minutes, just the time it took to remove one bolt; each man needed an hour to dress, to work 2½ minutes removing one bolt, then another hour to undress and shower.

The WTR incident now seems likely to be the first loss collected under NEPIA (Nuclear Energy Property Insurance Assn.). Amount of the loss cannot yet be estimated; guesses run above $500,000.

Decontamination is now nearly completed; meanwhile an additional heat exchanger for 60-Mw operation has been installed, and the reactor is slated to be back in operation this month.

QUEHANNA REACTOR TO BE SHUT DOWN

Curtiss-Wright confirmed last month that it plans to shut down its 1-Mw pool research reactor at Quehanna, Pa., and is considering leasing the facility, complete with five hot-cells, to another firm. A number have shown interest. Earlier some firms came in to discuss buying the reactor, before C-W decided on lease instead of sale. If a lessee does not take over in time to assure uninterrupted operation, AEC officials said C-W would have to get Commission approval for a deactivation program just as it had to for startup: "You just can't walk away and leave the fuel there," said one. Simultaneously Curtiss-Wright reorganized its staff, with all reactor activities being shifted to the Nuclear Radiation dept. at Princeton, N. J. This includes completion of four research reactor construction jobs: for Watertown Arsenal, Missouri Univ. School of Mines, Thailand, and—on subcontract to Lummus—Brookhaven's High Flux Reactor.

ASK FLORIDA REACTOR STRETCH-OUT

Florida West Coast and East Central Nuclear Groups have recommended to AEC a reoriented research program and a two-year postponement of the reactor's target completion date. Recent cost estimates have increased so sharply that the project is being redefined; Philip Sporn, head of ECNG, reported to AEC and JCAE that latest construction cost estimates—now placed at $29.5-million—exceed the limits of the original obligations by private utilities to the project. (ECNG is administering the entire research-development program for FWCNG and has agreed to finance $9-million of its $18-million cost, with AEC paying the other half and FWCNG the construction cost, originally set at $26-million. The contract with AEC says construction would be undertaken if power cost is not more than 150% of conventional power.) The reorientation of research is aimed at switching from stainless steel to beryllium cladding for the fuel elements and taking the necessary time to prepare beryllium for this role. Second main technical program is to fabricate pressure tubes having low neutron absorption cross section and able to stand prolonged irradiation. The projected 50-Mwe prototype would be pressure-tube, D_2O-moderated and gas-cooled, and would be built at a site near Tampa.

TWO NEW JOBS FOR M&C NUCLEAR

The first 1960 orders for nuclear navy cores—for three S5W submarine cores—went to M&C Nuclear (NU, May '60, 20). The Attleboro, Mass., firm was also picked to handle NS *Savannah's* spent fuel elements from pierside to reprocessing plant. M&CN is to provide "personnel and knowhow to monitor loading and unloading operations" in addition to furnishing and operating fuel transportation equipment, taking over shipments of spent fuel from the service barge at pierside.

NDA WINS MILITARY COMPACT REACTOR JOB

Nuclear Development Corp. of America has won out in a strongly-contested bidding competition over eleven rivals to be prime contractor for the Military Compact Reactor; General Motors will be subcontractor on the power conversion end. The AEC contract NDA and GM will get is for a one-year development and preliminary design study, not the expected final design and construction job; AEC is understood to feel the program's scope would be more sharply focused after one more year's work, before actual construction is undertaken. Earlier MCR studies had been limited to the reactor; the present study will be for a complete system. MCR is a compact, light-weight 2–3-Mwe power plant for a number of significant, classified military applications, including an overland tractor train, space vehicle use. Details are closely guarded on this project, only classified one at Army Reactors Branch—among other things because many of the problems are so close to those of the Aircraft Nuclear Propulsion program. The described compactness and light weight, however, have led to speculation that it may be a lithium-cooled fast reactor. Contract value is $3–4-million. MCR is said to have essentially no civilian application for a long time to come.

WORLD NEWS

Euratom to Operate Mol Center

Belgium's big nuclear research center at Mol will come partly under Euratom control under an agreement initialed last month. Euratom would operate for 20 years BR-2, the high-flux test reactor designed by the Belgians and Nuclear Development Corp. of America. A similar provision anent BR-3, the 11.5-Mwe Westinghouse pressurized water reactor, has not been finalized and may remain in abeyance. The agreement was seen in Belgium as a result of the government's drive to cut expenses because of the situation in the Belgian Congo. It was made conditional on amendment, by the Euratom Ministerial Council, of Annex V of the Euratom Treaty to permit Euratom to control more than one reactor. The six-nation pool is still negotiating to take over also the Dutch nuclear research center at Petten and the German at Karlsruhe, and is still awaiting ratification by the Italian Parliament of the agreement whereby Euratom would run Ispra.

Special Status Sought for SENA, Givet Builder

A new European utility grouping has added another set of initials to the atomic alphabet-soup. SENA—Société d'Energie Nucléaire Franco-Belge des Ardennes—was formally founded May 25 in Paris by Electricité de France and the Belgian group of utilities Centre et Sud, on an equal participation basis. SENA's purpose is to build the Centrale Nucléaire des Ardennes, a 150-Mwe power plant at Chooz near Givet—on a tongue of French territory extending into Belgium. Bids to build the plant by Atomics International, Babcock & Wilcox, General Electric and Westinghouse are still under consideration. Even before SENA became officially a reality, the Euratom Commission asked its Ministerial Council to grant the new group the special treatment as a "common enterprise" provided for in the Euratom Treaty (Articles 45–51 and Annex III). Such treatment would confer on SENA a number of advantages including tax-free and customs-free status—enough, Euratom said, to reduce power production costs 10–15%, although not enough to make the reactor competitive.

France Starts Reactor, Drops Another

Construction has begun on a French land-based prototype submarine reactor, at the new reactor testing site at Cadarache near Marseille. The long-planned project is a joint undertaking of the Defense Ministry and the Commissariat à l'Energie Atomique; a naval group under direction of a Navy engineering officer has been set up within CEA. The reactor will be fueled with enriched uranium supplied by the U. S. However there is no decision as to disposition of the partially-completed hull of *Q-244* at Cherbourg arsenal: its projected natural-uranium gas-cooled reactor has now long been abandoned as impractical. . . . Last month France quietly dropped one of the four developmental projects undertaken in July 1958 (NU, Aug. '58, 19). Brenda was to have been a reactor to study gas coolants at 1300° F—a 12–17-Mwth unit fueled with enriched uranium and moderated and reflected with beryllium oxide. Brenda was to have been built at Cadarache. No reason was given for dropping it.

IAEA, Euratom Reaffirm Demand for A-Power

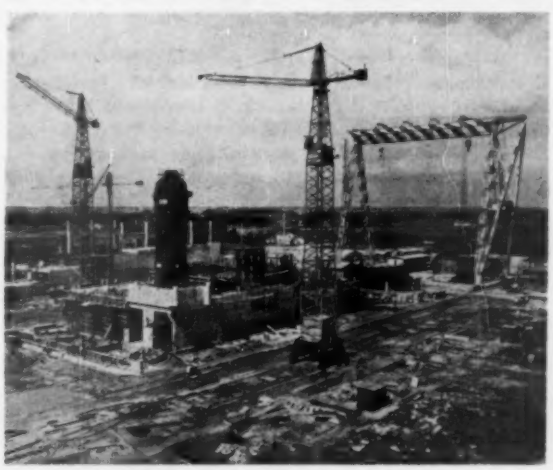
"The need for atomic power remains as great as ever," the International Atomic Energy Agency's annual report to the U. N. Economic and Social Council asserted. "If there has been some deferment of short-term expectations, it is probably because earlier appraisals underestimated the seriousness of the technological problems and were unduly influenced by transient economic and political factors." . . . Simultaneously, Euratom's President Etienne Hirsch was calling for a target of 40-million kwe by 1980 in spite of Europe's new sources of fossil fuel. Hirsch told the Parliament of the six-nation European Community in Strasbourg that the primary energy requirements of the six Euratom nations would rise from 460- to 800-million metric tons of coal equivalent between 1960 and 1980, and that reserves of coal and oil now known could not meet such a demand.

Sweden's R-2 Critical

One of the world's most powerful research reactors went critical in May at Studsvik, site of Sweden's nuclear research center. R-2, a 30-Mw pool-in-a-tank light-water-moderated and -cooled reactor, will produce 2×10^{14} flux for simultaneous irradiation programs in physics, chemistry and metallurgy.

No Distributor Yet for Latina Current

Italy's Latina reactor, being built by Britain's Nuclear Power Group, has no setup for distribution of the current it will make. Plans are that when the 150-Mwe Calder-type reactor being built for SIMEA reaches its



"dress rehearsal" period, the 75% of SIMEA owned (through Agip Nucleare) by ENI (Italy's national energy trust) will be turned over to Finelettrica, the power-utility subsidiary of IRI (the national industrial-development trust) which owns the other 25%; and at that time a distributing setup will be established. It is not yet clear, however, whether the power-distributing subsidiary will be single or a collection of cooperating companies. Finelettrica's present power network south of Rome may be used to distribute the power from Latina. Meanwhile construction is progressing (*see photo*).

Japan Starts Construction of Calder-type Plant

Japco—the Japan Atomic Power Co.—began foundation work last month on its 166-Mwe reactor, to be built for it by Britain's General Electric Co.; construction finally started after three years of studies, negotiations and preparations. The 57-acre site at Tokai had already been raised to 8 ft above sea level. Foundations for the $100-million reactor are to be completed by mid-November.

NEWS IN BRIEF

Interior Dept. Attacks ACRS, Drops Pt. Loma

AEC's Advisory Committee on Reactor Safeguards, which up to now has been virtually immune from public criticism, was attacked sharply last month by an official of the Interior dept. Former Midwestern Congressman A. L. Miller, chief of Interior's Saline Water Office, accused ACRS of advising against Pt. Loma, Calif., as a site for the saline-water conversion reactor on insufficient grounds. ACRS had suggested to AEC that the temperature inversion problem at that site and high population density were two good reasons for ruling out Pt. Loma (NU, Apr. '60, 30). Miller contended, however, that these were not valid reasons and that "if you can't go out there [Pt. Loma] with nuclear power plants you can't go any place." Moreover, he said, three AEC Commissioners said they agreed with him "100%." He warned that the ACRS attitude toward reactor safety was a threat to the entire power-reactor industry. "You can't let a committee that is a creature of Congress and that doesn't report to Congress make decisions of this type," he declared.

Miller's blast came as the Interior dept. announced it was dropping its plans to build a nuclear plant at Pt. Loma but, instead, would build a conversion system using natural gas. Miller said he would like to use a reactor in a proposed conversion plant at Roswell, N. M., when funds for this plant are appropriated.

Radiation Standards: Big Month in Washington

Two weeks of hearings on federal radiation protection standards completed last month by the Special Radiation Subcommittee of the Joint Committee on Atomic Energy —though developing no new scientific information—revealed some real differences among major U. S. scientists in setting radiation standards.

Sen. Clinton P. Anderson (D-N. M.) and Rep. Chet Holifield (D-N. M.) also made it clear they are unhappy about some aspects of the Federal Radiation Council, which issued new protection guides for all federal agencies in May. It was pointed out that, although FRC's guides bind all agencies regulating the nuclear activities of industry, the Council itself was not subject to the Administrative Procedures Act. Consequently, neither the public nor industry is allowed a voice in FRC's decision-making—nor can they appeal FRC actions.

It was also contended that FRC is not set up to consider adequately all of the effects of its safety criteria; JCAE would like to see industrialists, economists, social and political scientists and representatives of public and labor groups added either to the Council or its working groups. FRC Chairman Arthur S. Flemming, secretary of Health, Education and Welfare, agreed that social scientists should take part in FRC considerations but doubted that FRC could fulfill its basic advisory function to the President if it were subject to the Administrative Procedures Act.

FRC's New Guides. The FRC safety guides follow those of the National Committee on Radiation Protection and the International Commission on Radiological Protection. A new term, "radiation protection guide," was adopted in an attempt to formulate nomenclature which would remove the connotation of a threshold—and was presented by FRC in terms of the need for balancing risks against benefits in specific applications.

AEC Considering New Cross-Communication System

A new system for locating people working in a given area of research is under consideration by AEC. The system, CATE, has been under test for a year by the Air Force; CATE stands for Current ARDC (Army Research and Development Command) Technical Efforts. Described to many of the AEC staff at a meeting last month, the system works this way: those at work on a particular research project fill out simple punch cards defining the project in no more than six key words (a special dictionary is used). These cards are fed into a system which is then capable of feeding back, on request, the names of those working in specific areas.

U. S. Foreign-Reactor Aid Program Expires

AEC and State dept. officials said last month that the research-reactor grants-in-aid program—for friendly foreign countries—would not be extended beyond the June 30 expiration date. As many as eight applications expected to be pending at the deadline, however, will be processed for possible $350,000 grants, they said. As of the end of May nineteen U. S. reactors had been purchased with the help of these grants. Once all pre-June 30 applications have been processed, applications for research-reactor aid will be accepted under the U. S. general foreign-aid program but they will have to compete with the myriad nonnuclear projects constantly being considered under the foreign-aid program.

Nuclear People: New Commissioner, NAM Task Force

The Senate last month confirmed **Loren K. Olson** to succeed **John F. Floberg** as a member of the Atomic Energy Commission. Olson's term expires June 30, 1962. Floberg reports to Firestone Tire & Rubber as general counsel. . . . Meanwhile, **William Chamberlain** of AMF Atomics, who had been asked to join a task force on government competition of the National Assn. of Manufacturers (NU, June '60, 19), said he could not serve, was replaced by D. H. Loughridge, General Motors.

Direct Conversion Study Completed by Brookhaven

Brookhaven National Laboratory has completed a study for AEC on direct conversion—its status and potential for civilian power stations. It covers four major approaches: thermoelectric, thermionic, magnetohydrodynamic and fuel cells. Brookhaven's general conclusion is that it is not now possible to state clearly the potential of direct conversion in nuclear power. However, based on predictions of an expanding nuclear business over the next decade, it is felt that direct-conversion may find widespread use.

West Coast Firm Attacks AEC Waste-Disposal Policy

The Isotopes Specialties div., Nuclear Corp. of America, filed a strong protest against AEC's method of designating Oak Ridge National Laboratory and National Reactor Testing Station, Idaho, as interim land burial sites for low-level radioactive wastes. In a letter to AEC Chairman John McCone, the Division's general manager, Kenneth W. Newman, said he was not opposed to having the land-burial sites but rather to the fact that AEC was not providing for shipment of wastes via the waste-disposal firms presently handling ocean disposal. He claimed that such firms had played a major role in the proper packaging of wastes for shipment to disposal sites by AEC licensees and that these licensees would now be free to ship wastes to inland sites without this type of supervision. He told NUCLEONICS: "AEC [heretofore] has required disposal companies to run tests [at licensee's facilities] before waste is shipped. The new ruling removes many of the precautions that have been set up for expert disposal firms. The move was a definite result of political pressure [to halt sea disposal]."

RADIATION NEWS

Coast Guard to Test Isotopic Power for Navigation

The U. S. Coast Guard has asked AEC's Aircraft Reactors Branch to supply two isotopic-power devices for experimentation with USCG's navigational-aid equipment (buoys, etc.). ARB expects to order the devices on an 18-month delivery schedule. Buoys are now powered by batteries and have to be tended far more often than if they utilized such long-lived isotopes as strontium-90 or cesium-137. ARB is managing the procurement under its SNAP program (systems for nuclear auxiliary power).

Varian Gets QMC Go-Ahead on Food Linac

The Army Quartermaster Corps has instructed **Varian Associates** to proceed with completion of a huge electron accelerator ordered more than two years ago for the food-irradiation program. Work on the machine had been halted at 80% of completion when the Army reviewed the food program last year. Varian will complete the machine at 24-Mev and 18 kw for installation in the proposed food irradiation research center (site has yet to be selected).

Accelerators for Ion Propulsion Sold by 3 Firms

Goodrich-High Voltage Astronautics (subsidiary of B. F. Goodrich and High Voltage Engineering) has been given two ion-propulsion contracts by the Air Force's Wright Air Development Center: one for development and fabrication of a demonstration advanced engine using an arc-type ion source; the other for a design study leading to construction of an electrostatic generator for providing electricity to the ion engine. Prime energy for such sources, the company indicated, would likely come from nuclear reactors. . . . **Applied Radiation Corp.** has sold two Cockcroft-Walton machines to the National Aeronautics and Space Administration for delivery to Moffatt Field, Calif. They are for experimentation in ion propulsion. . . . **Radiation Dynamics, Inc.** has sold a 3-Mev, 10 milliamp Dynamitron, capable of producing positive ions and electrons, to Convair div., General Atomics, San Diego. (RDI also sold a 1.5 Mev, 15-kw electron accelerator to a Japanese firm for pilot-plant production of synthetic textiles, its fourth sale in two months.)

British Firms Plan 3 Big Cobalt Irradiators

Officials of the U. K. Atomic Energy Authority revealed last month that three 150,000-curie cobalt-60 irradiators are expected to be in commercial operation within 18 months. They would be built and operated by pharmaceutical and surgical-equipment concerns for sterilization of throw-away plastic hypodermic syringes, sutures, plastics catheters, etc. The plants will be patterned after the Wantage pilot irradiator, which has just gone into operation and in which 80% of capacity over the next year has already been allocated to the firms planning to build their own facilities.

The AEA will make cobalt available to the commercial plants at 70 cents/curie, NUCLEONICS learned, with specific activity of 1–5 curies/gm. The plants will be designed for 24-hr operation, 6 days/wk, delivering 2.5 megarads to as much as 2.5 tons product/day. Packages will be about the 1-cubic-ft size of Wantage's packages at an irradiation cost of about $1.50/package. Estimated construction cost of the plants is $150–180,000 each.

Meanwhile, U. K. authorities disclosed that they are cooling off to the possibility of building a cesium-separation plant. Design contracts for a plant of one-million-curie capacity were let nearly two years ago. But, in view of the availability of cobalt-60 used as a flux flattener in the U. K.'s power-reactor program, recovery of cesium is not now considered justifiable.

Nuclear-Chicago and Tracerlab Settle Geiger Dispute

The three-year-old dispute between Nuclear-Chicago and Tracerlab over Geiger-Mueller counting gases has been settled out of court. A Chicago Federal Court issued a consent decree after the settlement which said, among other things: "The defendant Tracerlab has infringed claims . . . of the patent [owned by Paul B. Weisz and licensed to N-C] by making, using and selling gas mixtures. . . . Tracerlab [is] hereby enjoined and restrained from making, using or selling, without license, any gas mixture for Geiger-Mueller tubes described in any claim of U. S. Patent 2,519,684 of Paul B. Weisz. . . . No damages for past infringement shall be awarded, defendant having paid, and plaintiff having accepted, a sum in settlement of all damages herein recoverable." Neither party would disclose the settlement sum.

Forum Again Seeks Nuclear Instrument Role

The Atomic Industrial Forum called a special meeting for June 29 to explore with **radiation-instrument firms** the possibility of expanding the Forum's role in the industry's problems. Key industry executives behind the meeting are Davis R. Dewey, president of Baird-Atomic; Ernest Wakefield, president of Radiation Counter Laboratories; and Nicholas Anton, chairman of Anton-Imco Electronics. Wakefield feels strongly that the Forum could meet the industry's needs for a trade-association type of organization (NU, May '60, 23).

Ameray Corp. Low Bidder on Walter Reed Irradiator

A New Jersey firm, Ameray Corp., Kenvil, was low bidder last month to supply a cobalt-60 irradiator to Walter Reed Medical Center for experimental irradiation of mice and guinea pigs. Ameray's bid was $13,000, including cobalt. Second was Atomic Energy of Canada, Ltd., winner in April to supply a test-tube irradiator to WRMC (NU, June '60, 28). AECL's bid was $19,000 for the mouse irradiator. All told 12 firms tendered bids, the highest ten times Ameray's bid, or $130,000. WRMC said it would make a selection from the low bidders by the end of June and go out on bid shortly thereafter for a larger cobalt irradiator for dogs.

Martin Building Lab to Develop Curium-242 for AEC

Completion was expected by end-June of a Martin Co. processing facility for development of curium-242 as a fuel for isotopic power sources. Working under a contract from AEC's Aircraft Reactors Branch, Martin will develop techniques for encapsulating americium-241 in aluminum. The capsules will be shipped to the Materials Testing Reactor, Idaho, for conversion to curium-242 by irradiation for about three months. Curium is attractive for isotopic power because of high-power density, potentially low cost as compared with polonium-210 and capability for fabrication in fuel forms which meet the requirements of thermionic direct-conversion devices.

Forum Publishes 1954–58 Statistics on A-Industry

A monumental yet naggingly frustrating report was issued last month by the Atomic Industrial Forum: its first statistical report on the industry.* Among its salient findings: $660-million worth of nuclear products and services are estimated to have been delivered by U. S. industry in 1958, $1.5-billion in the five-year period 1954–58. AEC spent less than 10% of its research-and-development funds for work done in industry facilities; companies outdid AEC in supporting such work. In 1954–58, $465-million private capital was invested in facilities.

Owing almost entirely to the obstacles, complications and pitfalls peculiar to the industry, the report—as has been said of statistics generally—is like a bikini swimsuit: what it reveals is interesting, what it doesn't show is vital. Some of the problems for readers:

- The Forum decided to focus on commercial activities, and exclude government facilities. Thus, left out are not only naval, aircraft and rocket propulsion work, Oak Ridge, Fernald, Hanford and Savannah River, and work carried on in national labs, but even Shippingport, the Sodium Reactor Experiment, the Idaho reactors. This would make for consistency (if also incompleteness)—but producers of nuclear materials, sub-subcontractors on instruments, etc., often are unaware of the end-use of their product.
- The Forum solicited data from 1,121 companies and institutions. 477 (42%) replied—but of these, 34% (161 firms) reported they were not in the nuclear field.
- In general, the incomplete response by companies to the Forum questionnaire makes it difficult to tell what the numbers mean. The Forum made some projections to get estimated industry-wide totals, which are useful, even though not firm.

Other criticisms could be made: the numbers are old, going only through 1958 (the Forum plans to compile 1959 figures shortly); the tables are excellent compendia but difficult to interpret. But the criticism should be leveled not at the Forum, which has made a fine start on a badly-needed but exceedingly difficult job—but rather at the companies that failed to furnish data. It is much to be hoped that the Forum's second volume will be truly industry-wide.

* "Business Statistics on the Atomic Industry 1954–1958," Atomic Industrial Forum, New York, $3.50.

NUCLEONICS Statistics of the Quarter

Costs of U. S. Civilian Reactors in Progress ($10³)†

	Total Cost of Projects	Costs, '60 1st quarter	Costs thru 3/31/60	Still to be spent
Power prototypes & experiments	783,402	44,267	339,751	443,651
—Research & development:				
AEC	137,497	7,614	69,152	68,345
Electric utilities	61,749	1,603	39,436	22,313
—Plant, equip't., fuel fabrication:				
AEC	143,725	9,688	37,758	105,967
Electric utilities	440,431	25,362	193,405	247,026
Savannah propulsion plant	29,000	1,096	15,966	13,034
Research & test reactors	116,245	5,896	65,442	50,803
AEC	73,839	4,367	35,036	38,803
Other govt. agencies	14,649	215	12,383	2,266
Manufacturers & universities	27,757	1,314	18,023	9,734

	Latest month	Month ago	Year ago
Nuclear Contracts *—			
Contracts awarded for public projects ($10³)	1,862	6,360	129,265
Proposed construction, privately-owned ($10³)	0	0	0
Contracts awarded, private work ($10³)	1,305	0	0
Backlog of private projects ($10³)	287,549	287,549	285,549
Isotope Use †—			
Applications for isotope use	721	668	651
Cumulative total of isotope users	5,680	5,617	4,867
ORNL shipments (curies)	19,976	10,783	63,900
Public and private export shipments	836	463	276
Employment †—			
AEC employment	6,767	6,670	6,676
Construction and design contractor's employment	9,915	9,176	7,490
Total operating constractors employment	103,855	104,143	104,434
Production workers	51,087	51,078	51,761
Research and development employees	48,144	48,396	47,254
Miscellaneous workers	4,624	4,669	5,419

U. S.-built Reactors ‡—

	Operating	Building	Contracted
Power, domestic	2	10	5
Power, for export	0	5	1
Power experiments and pilot plants	6	6	2
Military and naval	21	41	8
Research and test, domestic	68	19	52
Research and test, for export	19	20	4
Total	116	101	72

Foreign-built Reactors ‡—

Power, domestic	18	21	12
Power, for export	0	3	1
Research and test, domestic	39	7	13
Research and test, for export	8	6	1
Total	65	37	27

* From *Construction Daily*, a McGraw-Hill periodical † From AEC ‡ NUCLEONICS figures

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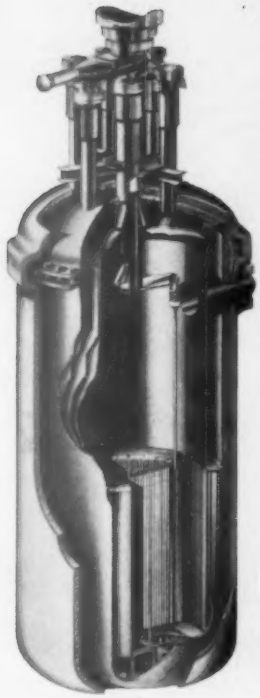
MARCOULE FRANCE: Reprocessing Plant designed, built and set into operation by the SAINT-GOBAIN Company for the French Atomic Energy Commission.

HTGR / Prototype Plant To Be Completed by 1963



Reactor core — High Temperature Gas-Cooled Reactor

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Inquiries are also invited from qualified physicists, metallurgists, chemical and electrical engineers, and mathematicians-programmers. For further information on openings write: Manager of Personnel, General Atomic, P.O. Box 608, Dept. 18, San Diego 12, California.

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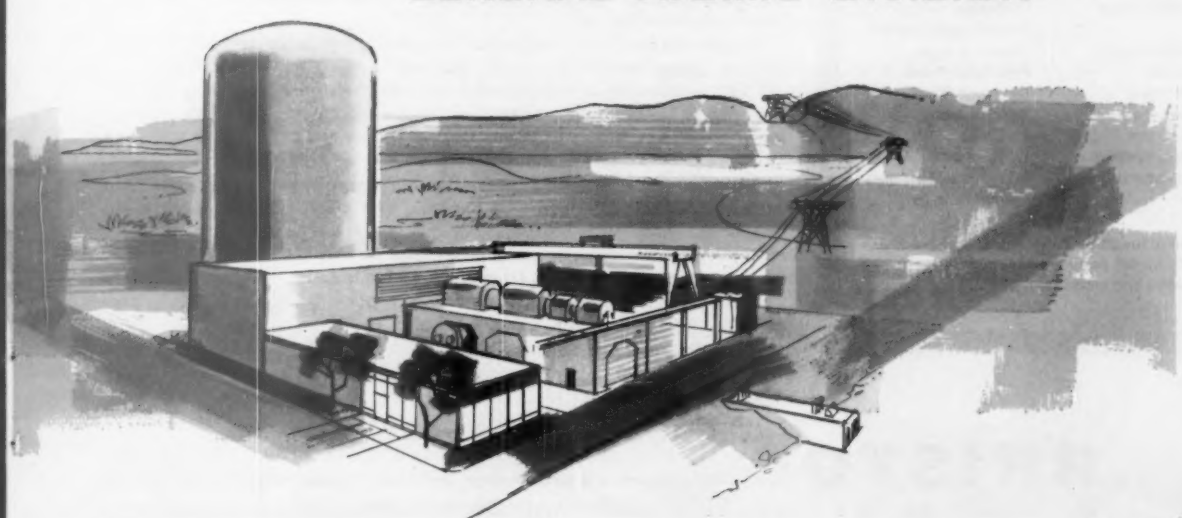
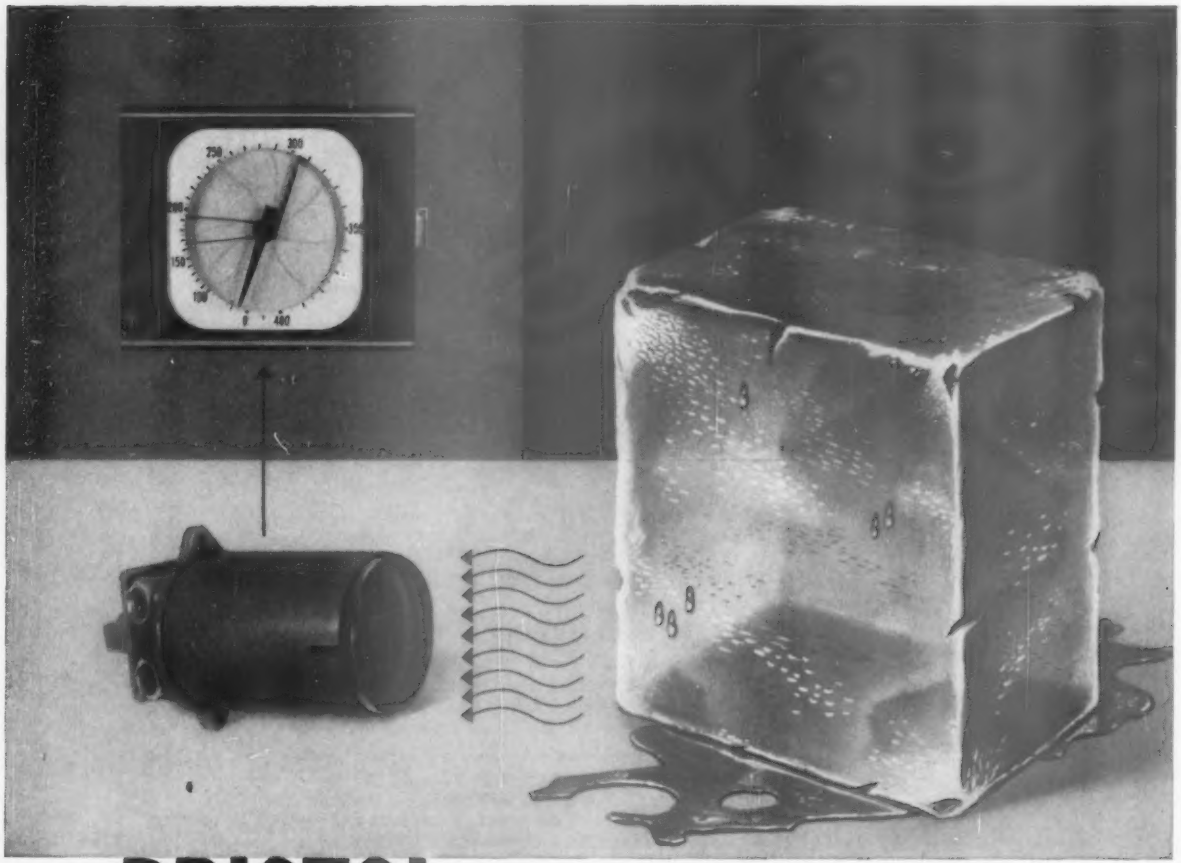
GENERAL ATOMIC DIVISION





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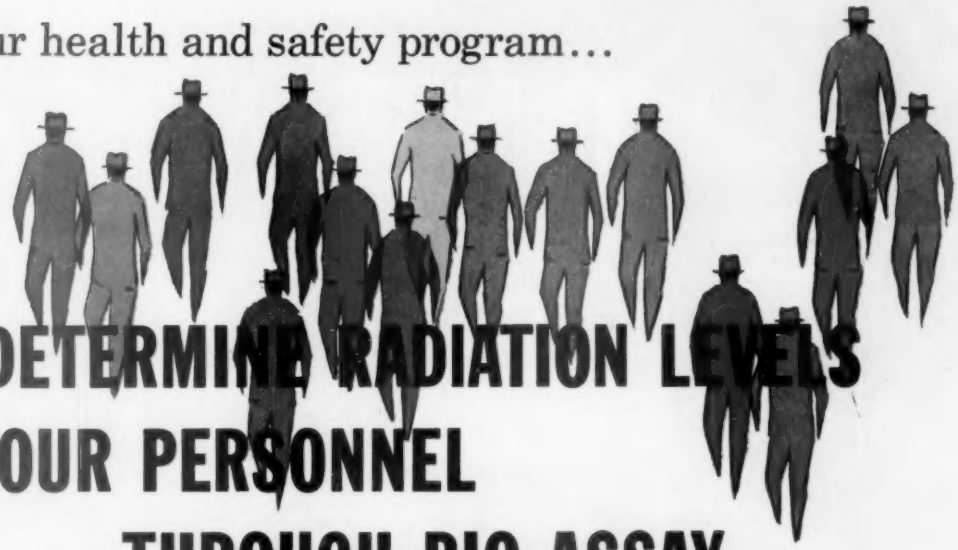

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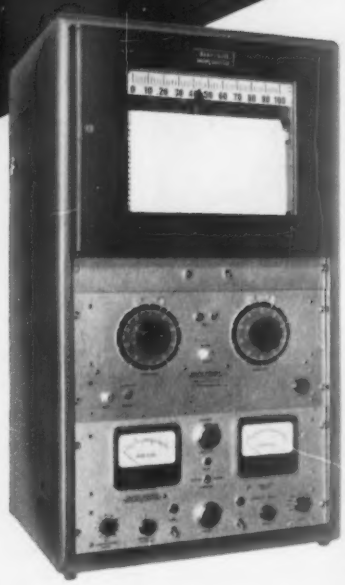
RADIATION SPECTROMETERS



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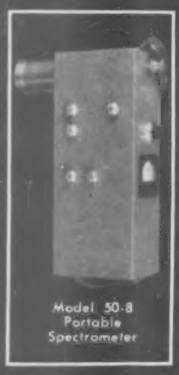

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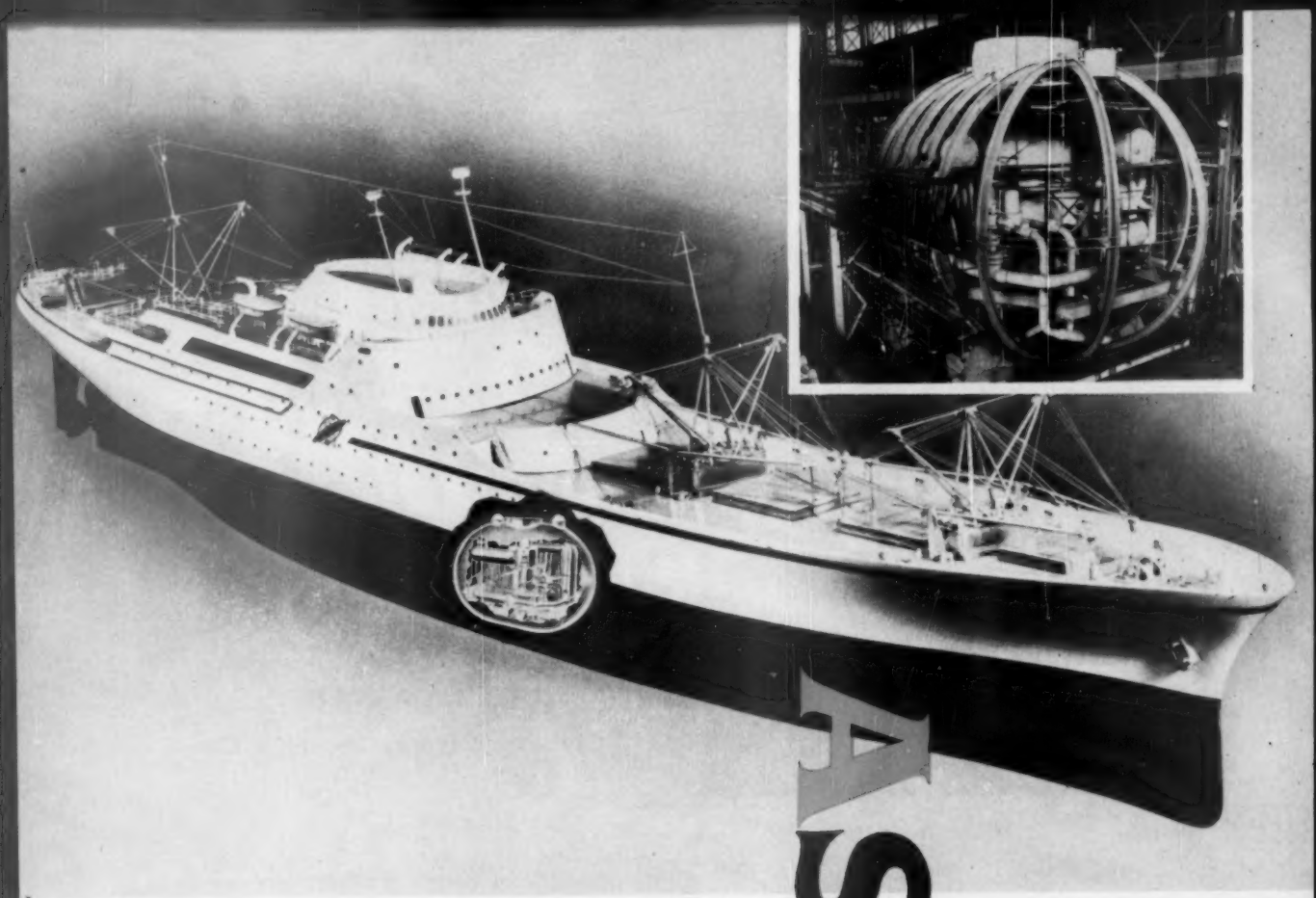

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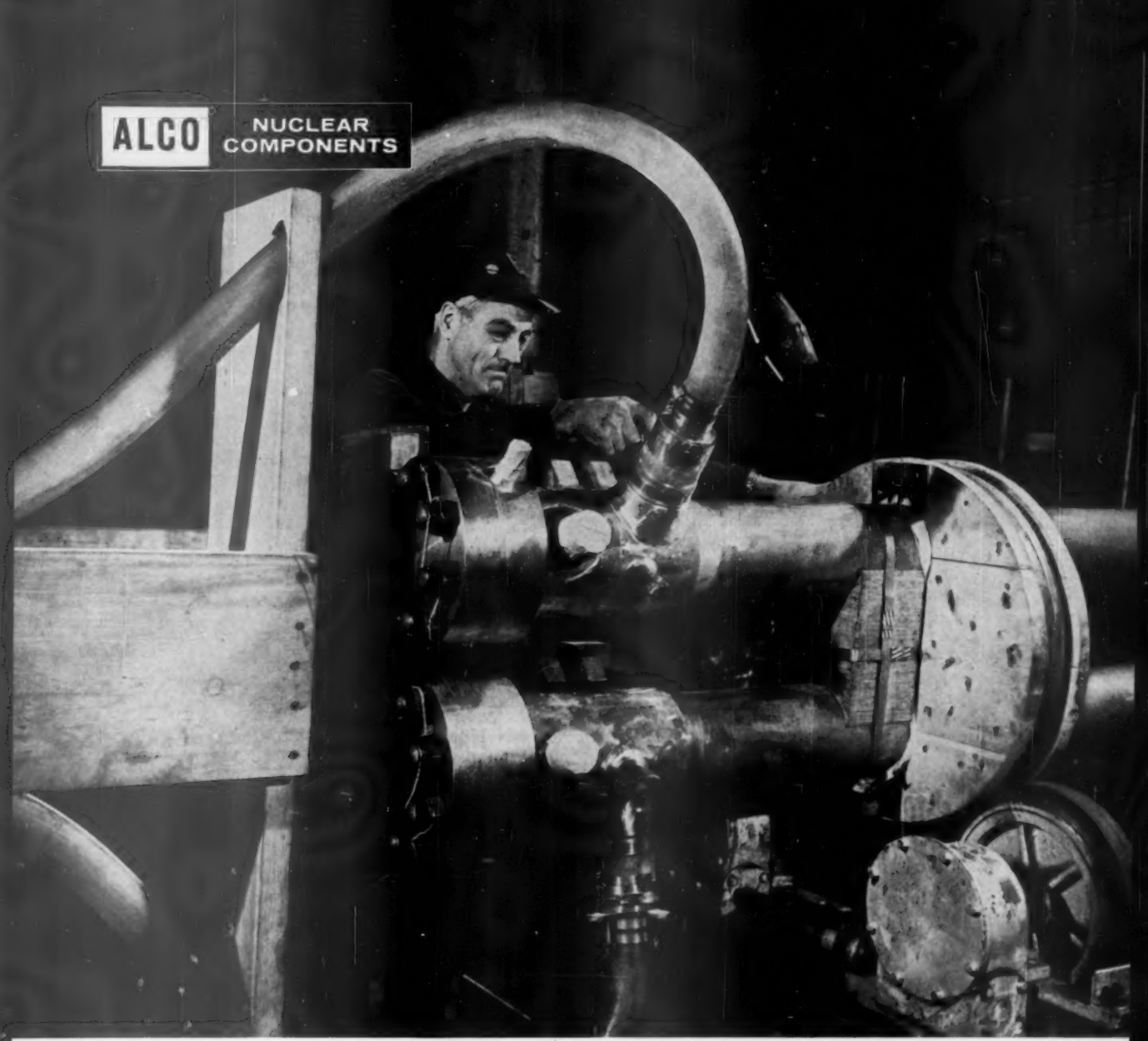

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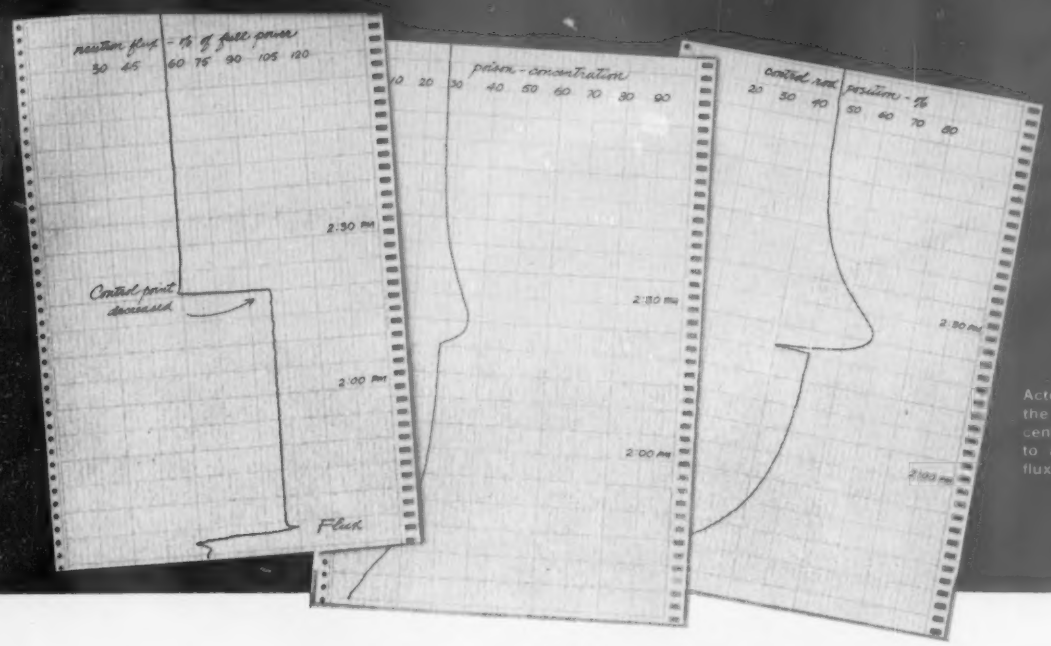

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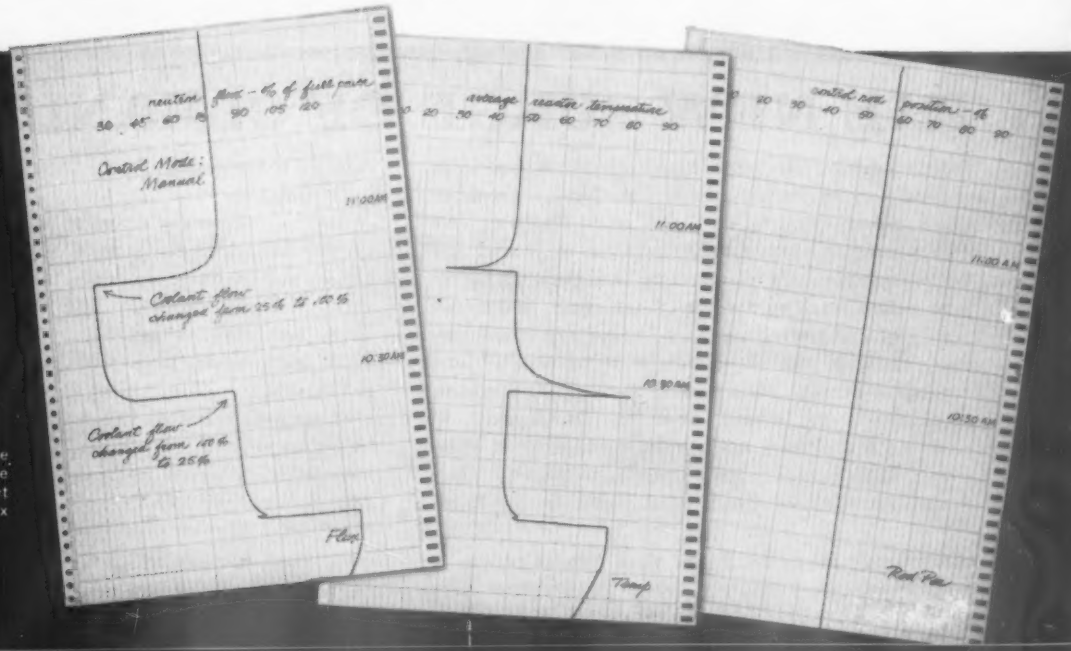
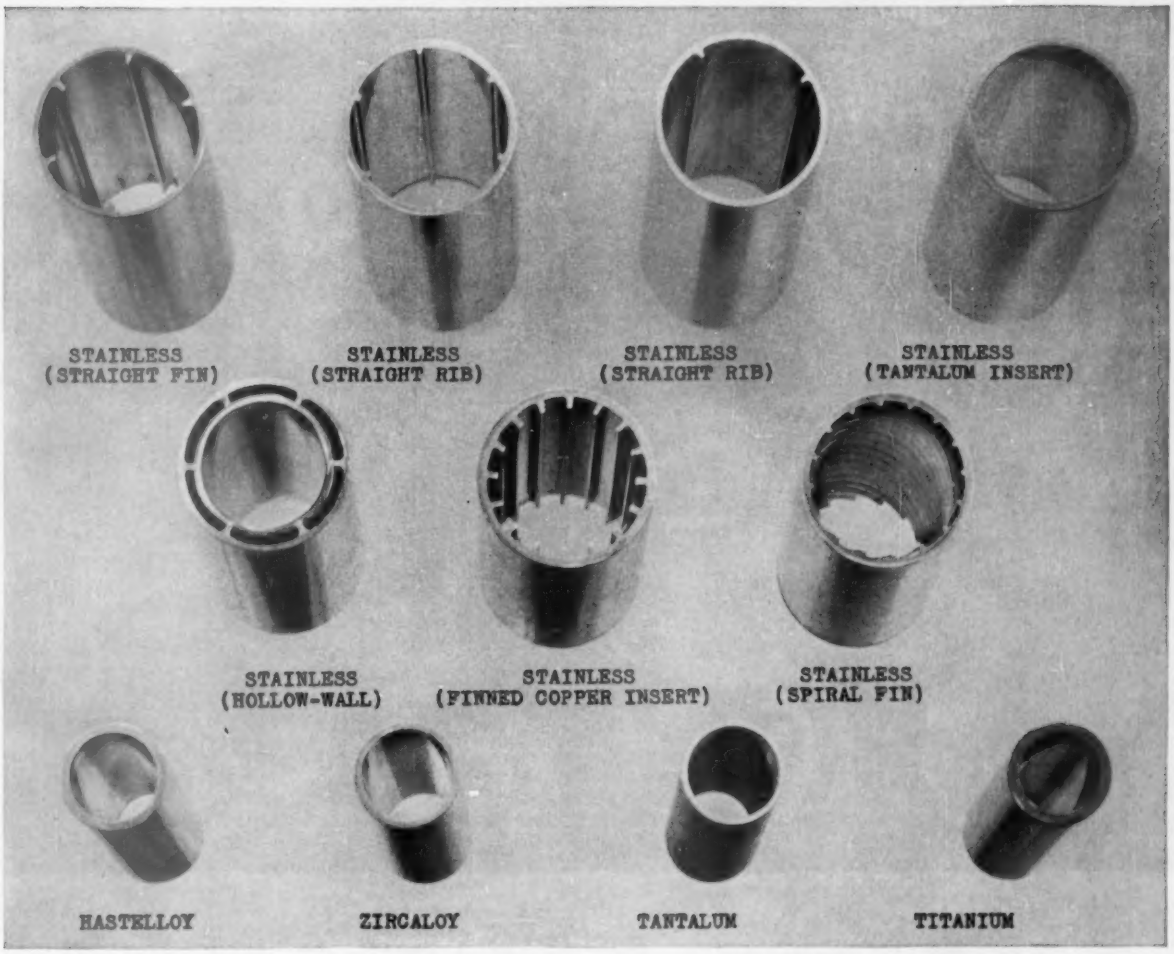

neutron flux - % of full power
average reactor temperature
control rod position - %
Control Mode: Manual
Coolant flow changed from 25% to 100%
Coolant flow changed from 100% to 25%
Flux
Temp
Rod Pos

These records show the stabilizing effects of the average reactor coolant temperature on neutron flux with manual control.



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LAND— Every major nuclear power station under construction in the United States will use Worthington equipment. Above, a Worthington engineer discusses the installation of a 120,000 sq. ft. condenser in the Dresden Nuclear Power Station in Morris, Illinois. Worthington successfully solved many unusual problems in the design of this condenser including the necessity of handling full output of dump steam.

SEA— All of the Navy's 25 nuclear vessels in operation or under construction will carry important items of Worthington equipment. This is the Ballistic-missile Submarine George Washington. Three Worthington high-pressure, 4500 psi air compressors furnish pressurized gas to expel the IRBM's from their tubes. These compressors will also be used for torpedo ejection, water ballast control, and to help operate escape hatches, periscope, antennae and other mechanisms.

AIR—Portable Nuclear Power Plants which can be flown to remote locations are a reality because of such technical achievements as Worthington's aluminum tube condenser. Built for Alco Products, it will be a vital part of a nuclear plant installed in a tunnel located beneath the Arctic snow. The unit is 75% lighter than conventional condensers. It meets a 15-ton weight limitation for Air Force transportation.

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Worthington serves the nuclear industry

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Worthington solved many special problems in the design of *condensers* for both the Enrico Fermi and Dresden Nuclear Power Plants. Special *high-pressure air compressors* were built by Worthington for installation in ballistic-missile nuclear submarines. Worthington also made significant design contributions to the *canned rotor pump* for circulating primary collant in reactor systems. The N.S. Savannah will go to sea with Worthington *buffer seal charging pumps*, a noteworthy application and design. A Worthington *turbine generator* is being used in the Argonne Low Power Reactor, a prototype nuclear packaged power plant for use in remote areas.

Your inquiries are invited. Please write to R. H. Davis, Manager, Marine and Nuclear Dept., Section 106-5, Harrison, New Jersey.

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WORTHINGTON

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You'd think their fate would have taught us a lesson.

Yet today we Americans spend twenty billion dollars a year for legalized gambling, while we spend a niggardly four-and-a-half billion for higher education. Think of it! Over four times as much! We also spend six-and-a-half billion dollars a year for tobacco, nine billion dollars for alcoholic beverages, and billions more on other non-essentials.

Can't we read the handwriting on the wall?

Our very survival depends on the ability of our colleges and universities to continue to turn out thinking men and women. Yet today many of these fine institutions are hard put to make ends meet. Faculty salaries, generally, are so low that qualified teachers are leaving the campus in alarming numbers for better-paying jobs elsewhere.

In the face of this frightening trend, experts estimate that by 1970 college applications will have doubled.

If we are to keep our place among the leading nations of the world, we must do something about this grim situation before it is too late. The tuition usually paid by a college student covers less than half the actual cost of his education. The balance must somehow be made up by the institution. To meet this deficit even the most heavily endowed colleges and universities have to depend upon the generosity of alumni and public spirited citizens. In other words, they depend upon *you.*

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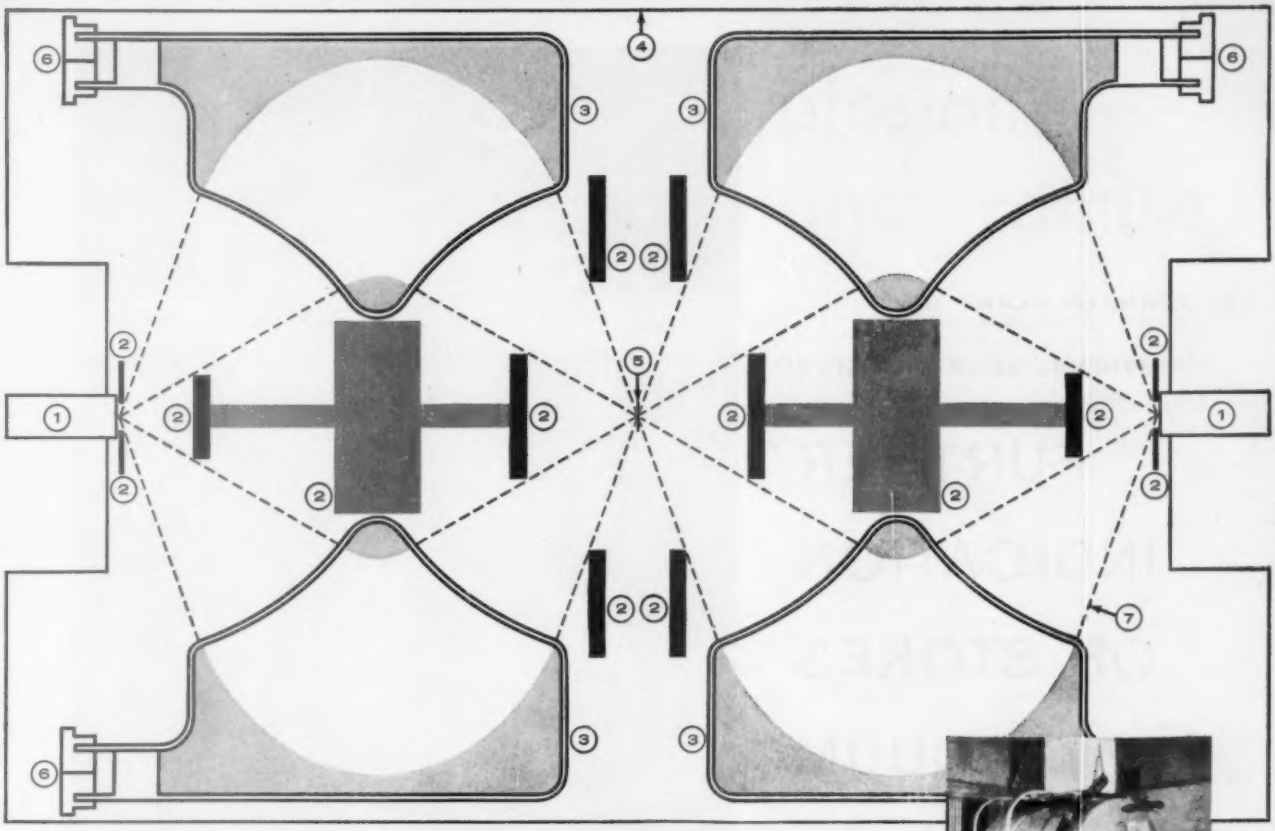
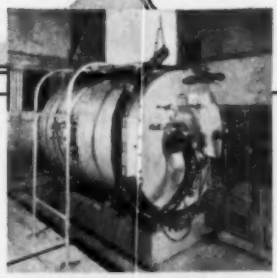
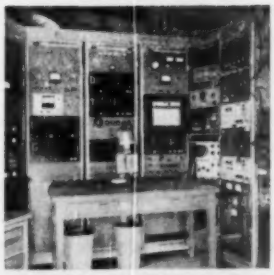
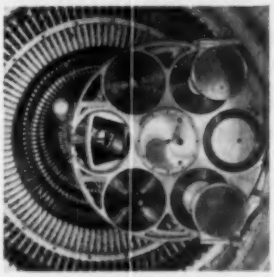
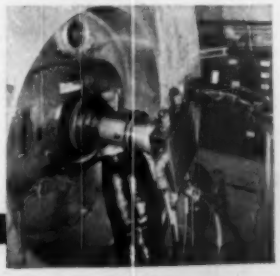


1 Detector, **2** Baffle, **3** Spectrometer Coil, **4** Vacuum Chamber, **5** Beta Radioactive Source, **6** Cooling Water Supply, **7** Dashed lines represent beta-ray trajectories in the instrument.









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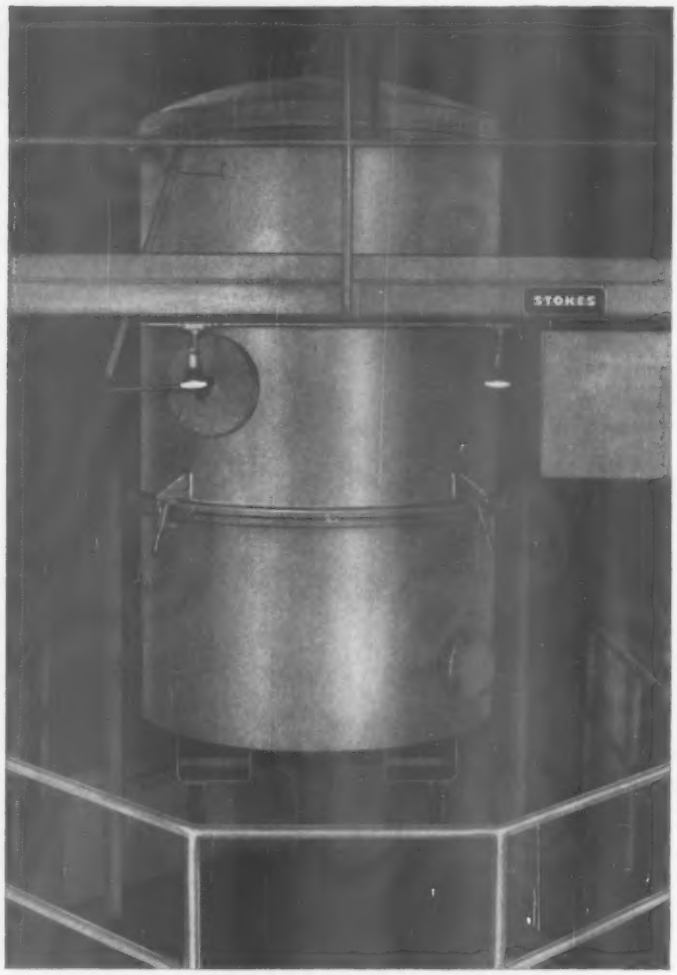

Stokes Vacuum Induction Furnace casts uranium ingots at the Fernald plant of National Lead Company.

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Peaceful Nuclear Explosions: Status and Promise

Instituted after the encouraging '57–'58 underground test series, AEC's Plowshare Program has laid plans for new underground experiments that would advance the science and technology of peaceful explosions

By GERALD W. JOHNSON, *Lawrence Radiation Laboratory, University of California, Livermore, California*

PEACEFUL APPLICATIONS of nuclear explosives became a practical possibility with the development of nuclear explosions that involve only small fission contributions. Fusion fuels are extremely abundant and cheap; the products of the fusion reaction are nonradioactive and the induced activity can be limited by neutron-absorbing blankets. The major problem in applying such explosions to constructive uses has been the radioactive products from the (relatively small) fission contribution to the explosion. However, experience has shown that in many situations, even for purely fission explosions, the release of radioactivity to the biosphere can be adequately controlled (*1*).

Consequently the Plowshare Program was established at the Lawrence Radiation Laboratory by the AEC in 1957, to explore the potential industrial and scientific uses of nuclear and thermonuclear explosives.

The objectives of the program are:

- To develop an understanding of the basic phenomenology of nuclear and thermonuclear explosions in various environments
- To explore possible industrial and scientific applications
- To plan and execute field experiments to gather additional data, conduct scientific experiments, and demonstrate industrial potentialities
- To design, develop, and test special explosives appropriate to any desired use.

The broader goals of the program are to reduce the cost and the radioactivity production of the explosives. As a guide to costs the AEC has published charges that would be appropriate to providing an explosive and the service of firing for various energy releases. The charges are $0.5-million for the kiloton range, $0.75-million for the tens of kilotons range and $1.0-million for the megaton-range explosives. To get total costs of experiments, of course, one must add the construction, operational, and scientific costs. A good illustration is Project Gnome (to be described later), where the total cost will be about $4-million including the AEC charges for the 10-kt (kiloton) explosive.

Knowledge to Date

Table 1 lists the nuclear detonations to date which have been most extensively studied. All of these explosions were conducted either to test new weapons designs or principles or to collect data about military effects. None of the explosions were conducted under the auspices of the Plowshare Program. The first completely con-

TABLE 1—Underground Nuclear Explosion Data

Test	*Date*	*Yield, W (kt)*	*Medium*	*Depth, D (ft)*	*Scaled depth, D/W$^{1/3}$*	*Measured radioactivity deposited on surface (%)*	*Crater volume (10^3 yd^3)*	*Crater volume/kt (10^3 yd^3/kt)*
Jangle-S	11/19/51	1.2 ± 0.1	Alluvium	−3.5*	−3.3*	65	1.65	1.4
Jangle-U	11/29/51	1.2 ± 0.1	"	17	16	80	37	31
Teapot-Ess	3/23/55	1.2 ± 0.1	"	67	63	90	96	80
Neptune	10/14/58	0.115 ± 0.015	Bedded tuff	99	205	1–2	22	190**
Blanca	10/30/58	19.0 ± 1.5	"	835	310	0.5	0	0
Logan	10/15/58	$5.0^{+0.2}_{-0.4}$	"	830	485	0	0	0
Rainier	9/19/57	1.7 ± 0.1	"	790	670	0	0	0
Tamalpais	10/8/58	0.072 ± 0.010	"	330	780	0†	0	0
Evans	10/28/58	0.055 ± 0.030	"	840	2,200	0‡	0	0

* 3.5 ft *above* surface. ** In bedded tuff under a sloping surface 1:3; therefore, crater is probably larger than on a level surface. † No breakthrough to surface but radioactive gases in large quantities leaked into the tunnel. ‡ No breakthrough to surface but stemming failed, releasing gross fission activity into the tunnel.

tained underground nuclear explosion (code-named Rainier) of September 19, 1957, was conducted to develop a method of nuclear weapons testing that would not release radioactivity to the atmosphere. The experiment was completely successful and has provided most of our understanding of such explosions; other underground explosions followed as part of a development series.

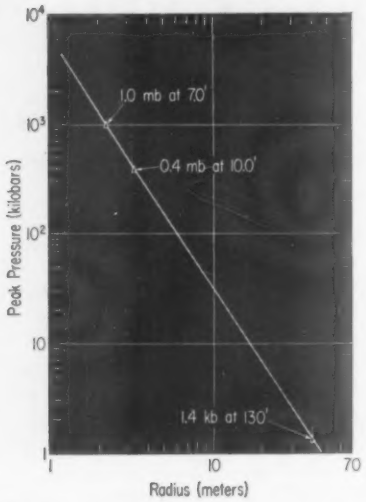

FIG. 1. SHOCK STRENGTH as function of radial distance from origin for Rainier event

Extensive drilling, logging, and mining operations have given us general information about the effects of these explosions. A theoretical model, developed for high-speed computers, seems to give the proper distributions of energy and correct magnitudes of the mechanical effects. The phenomenology of an underground explosion can be described in four stages characterized by very different time scales; let us take the Rainier explosion (*3–5*) as an example:

Nuclear reaction (microseconds). The total energy of the reaction is released in less than 1 μsec. In the Rainier explosion [in which an energy release of 1.7 kiloton (7.2×10^{19} ergs) took place in a $6 \times 6 \times 7$ ft room containing about one ton of material] the pressure in the room, after a few microseconds, was 7×10^6 atm and the temperature about $10^{8\circ}$ K. Accompanying the large energy release was a burst of neutrons amounting to 2×10^{23} per kiloton of fission energy.

TABLE 2—Partition of Energy in Rainier Event

State	*Radii (ft)*	*Percentage of prompt energy*
Gas	0–62	8.2
Liquid	62–62.25	19.1
Crushed	62.25–130	47.0
Fractured	130–180	21.2
Elastic	280	4.5

Hydrodynamic phase (milliseconds). Under the influence of the high pressure the room expanded in a few tens of milliseconds to a spherical cavity 125

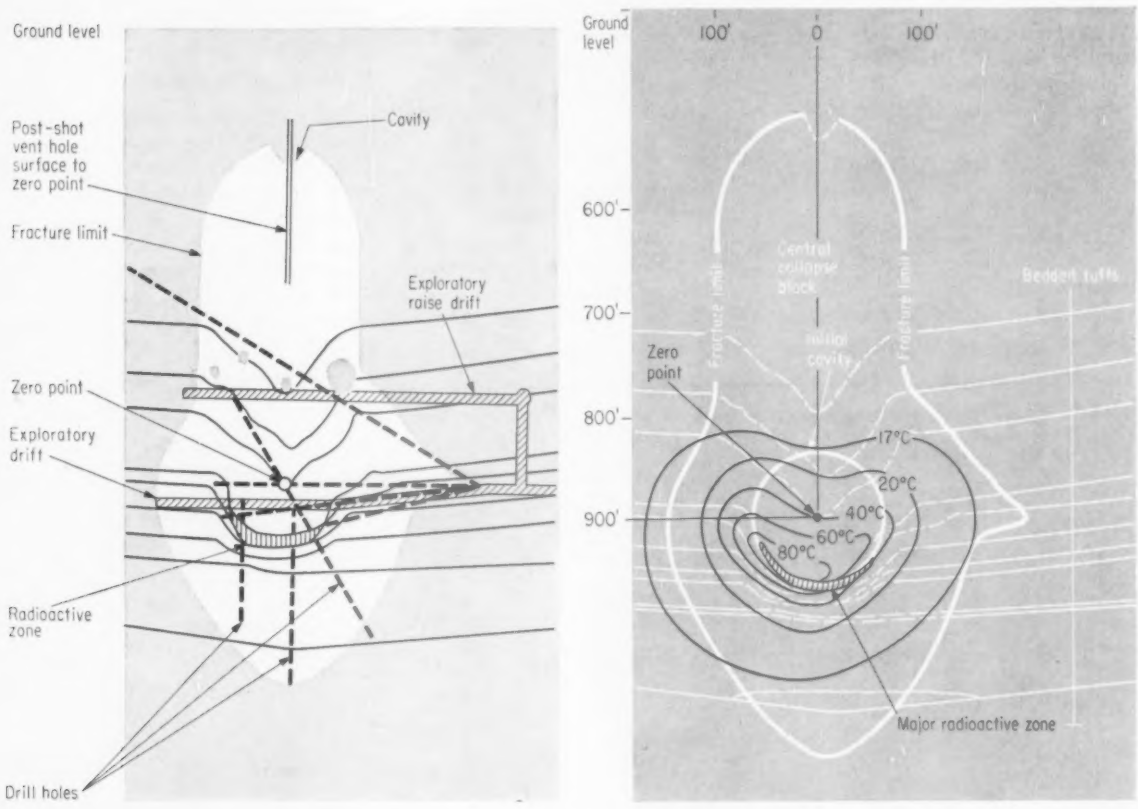

FIG. 2. RAINIER POST-SHOT DATA. (a) Vertical section through blast region shows shift of earth layers within fracture zone. (b) Temperature distribution 5 months after event; background temperature is 16.6° C. Sphere labeled initial cavity is formed during first stage of explosion and is then filled in by collapse of overburden

ft in diameter. At this time the cavity was lined with a shell of melted rock about 4 in. thick, which amounts to an estimated 800 tons of material. The temperature and pressure were 1,200–1,500° C and 40–50 atm respectively. The shock proceeded outward crushing the rock to a radius of 130 ft and becoming elastic at 280 ft. The elastic wave proceeded beyond that point until attenuated. For a sufficiently large explosion (~20 kt at the Nevada site) the seismic signal can readily be detected at several thousand miles. Figure 1 shows the shock strength as a function of radial distance and Table 2 the calculated partition of energy during this phase.

Quasi-static phase (seconds–minutes). The cavity persisted for seconds to minutes, during which time melted material flowed down the sides and dripped from the overhead. This stage ended when the roof collapsed; the temperature then dropped rapidly because of the rapid expansion of the gas and dilution by the cold material falling in. The melted rock froze to a glassy material and collected in a bowl-shaped zone toward the bottom of the cavity. This glass contained 65–80% of the gross fission-product activity. The remainder was distributed through the collapsed zone. Because the rock contained 15–20% water by weight and there was a large permeable zone, the temperature of the hot rock rapidly fell to the boiling point of water.

Long-term phase (>minutes). Successive collapse of the cavity vertically, slow thermal diffusion, and radiation decay continue. For Rainier the vertical collapse proceeded upward about 400 ft and then apparently stopped. The temperature distribution measured five months after detonation is shown in Fig. 2b.

Detailed geological mapping by coring and mining of the collapsed zone revealed the general structure shown in Fig. 2a. The features of interest are the radioactive zone at the bottom, the collapsed zone extending upward to form the chimney, and the fracture boundary about 65 ft below the point of detonation to about 400 ft above it. The natural bedding of the tuffs made it easy to identify movement of material into the collapsed cavity. At about the level of detonation, the rocks grade from a few inches in diameter just inside the radioactive shell to several feet in diameter at the center. The boundaries between the rocks were filled with a fine dust, which one year after the explosion had recemented.

The explosions as a group support the following generalizations for tuff (extending them to other media must be done with caution):

- The radioactivity of nuclear explosions in the kiloton range in tuff can be completely contained underground at depths of $D = 400W^{1/3}$ ft or greater, where W is the energy release in kilotons.
- The initial cavity formed by the explosion has a radius of $R = 50W^{1/3}$ ft (for an overburden depth of 900 ft).
- Initially melted rock, which is converted to glass on cooling, amounts to 500 ± 150 tons per kiloton of energy release.
- The collapse of the cavity produces a zone of about 7×10^4 yd³/kt (1.2×10^5 tons/kt) of broken permeable material.
- The major portion (65–80%) of the gross fission-product activity is in dilute (1 part per 10 million) solution in glass. The remainder (20–35%) is distributed throughout the collapsed zone of the chimney and is deposited on the surface of the broken material.
- About 30% of the total energy release of the explosion is initially deposited in steam and hot rock at a temperature in excess of 1,200° C. The temperature rapidly degrades to the boiling point of water. One year after the Rainier explosion this energy resided within a volume whose radius was less than 80 ft.

FUTURE PLANS

The series of tests of Table 1 prompted proposals for several new experiments under the Plowshare Program. Three of the experiments are now in an advanced state of planning and one of these, Project Gnome, has entered the construction phase. Other experiments are in various degrees of preparation.

Project Gnome

One of the striking results of the Rainier study was the fact that such a large fraction (30%) of the total energy was initially deposited in hot debris (>1,200° C). Because of the large quantity of water present, the temperature was rapidly degraded, but what would have been the result in a dry medium? Perhaps the energy could be stored at high temperature long enough to permit recovery for power. These observations soon led to the idea of an explosion in a large natural salt formation which normally is dry (less than 1% water). With more detailed thinking and planning an experiment called Project Gnome has been designed in which a 10-kt all-fission explosion will be set off at a depth of 1,200 ft in a massive salt bed near Carlsbad, New Mexico. The general arrangement shown in Fig. 3 includes a 1,200-ft vertical access shaft which is joined at the bottom to a 1,000-ft tunnel. The tunnel terminates in a hook (similar to that used for the Rainier explosion) designed to be selfsealing as far as release of radioactivity to the shaft is concerned.

The basic objectives of the experiment are:

- To explore the feasibility of converting nuclear explosive energy into sensible and latent heat which could be used to produce electric power.
- To investigate the feasibility of recovering from natural salt useful isotopes produced during the explosion. The chemical and physical behavior of a large number of elemental species will be studied with no specific attempt to produce useful isotopes, except as required to establish feasibility.
- To extend the data on the characteristics of an underground nuclear

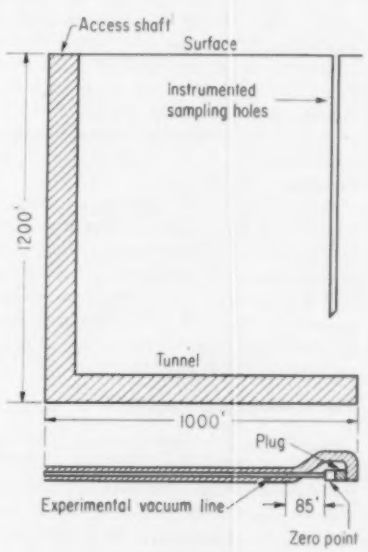

FIG. 3. PROJECT GNOME, now under construction, will test retention of high temperature heat in salt bed

explosion to a new medium (natural salt) that has physical properties in marked contrast to those of volcanic tuff—the only medium for which such data are presently available.

• To conduct several basic neutron-physics experiments (see p. 54).

The experiment is completely designed and construction was recently authorized to proceed in an announcement by President Eisenhower in May. If the project continues according to schedule, the experiment can be conducted in late 1960 or early 1961. The actual firing of the test, however, has still to be authorized.

Two other Plowshare experiments have reached the final stage of planning; these are Project Oil Sand and Project Chariot. Unlike Project Gnome they have not yet been authorized to begin construction.

Project Oil Sand

The Richfield Oil Company, in association with other oil companies and in cooperation with the AEC, has developed an experiment (Project Oil Sand) (*6*) directed toward releasing oil from the Athabaska tar sands deposit in the province of Alberta, Canada.

These deposits are estimated to

Scientific Data from Plowshare

Besides demonstrating the feasibility of practical engineering assignments such as power generation, oil recovery and large scale excavation, Plowshare experiments will provide unique opportunities to accumulate basic scientific data. The following represent only a few of the suggestions made along these lines at the Second Plowshare Symposium (9):

Space Research

The high-altitude nuclear explosions (Project Argus) set off by the United States in 1958 gave rise to important and spectacular auroral and geomagnetic disturbances. While these were classified military tests, much information has been published. The important characteristics of explosions in space are:

• One-half of the energy is released as thermal radiation characteristic of source temperatures of several million degrees.

• One-third of the energy is carried off as kinetic energy of the bomb debris.

• The remaining energy is divided between prompt and residual nuclear radiations.

Several individuals (*10–17*) have discussed possible uses of nuclear explosions to study the properties of space. The sharp thermal-radiation pulse would allow precise measurements of the propagation velocity of electromagnetic radiation in space. Squire and Softky (*18*) have suggested an experiment which would establish *relative* velocities of photons in four frequency ranges [rf range (100–1,000 Mc), optical range, X-ray ranges (few kev) and gamma-ray range (few Mev)]. The measured relative velocities should be good to ± 10 meters/sec. To confirm, or deny, the frequency independence of the velocity of electromagnetic radiations over such a wide band would be important to the theory.

The rich source of beta rays can be used to excite the auroras to levels exceeding natural excitations by many orders of magnitude. The advantages in such studies of being able to predetermine time and point of injection are obvious. Explosions in space also perturb the earth's magnetic field and hence provide a means of generating and studying the magneto-hydrodynamic waves. The nature of the radiation belts and the trapping and injection of particles can be investigated.

Transplutonic Isotopes

Einsteinium (99) and fermium (100) were originally discovered when they were produced in the first thermonuclear explosion of 1952. The highest mass number obtained was 255, the result of 17 successive neutron captures. This explosion was a weapons-development test on the surface, and the samples recovered were minute indeed.

A specially designed system combined with underground detonation, might recover milligram amounts of Cf^{253} from a single explosion. A reactor radiation program of several years duration is now underway to produce equivalent amounts of this isotope, which is unique as a laboratory source of fission neutrons and fission fragments. With appropriate design, measurable quantities of an isotope of mass 270, which would be expected to be stable at Z of 104, might be also produced and identified.

Earth's Structure and Seismology

Most of our understanding of the internal structure of the earth has come from analysis of signals generated by earthquakes. However, signals from nuclear explosions set off during weapons development tests have also contributed information (*19–20*). The output from four bombs fired in Central Australia in 1956, gave the first reliable information on the depth of the Moho discontinuity in Australia. The major uncertainties in earthquake seismology are time, source energy and location and depth of focus of the generating source. With a nuclear source, on the other hand, the location, time of detonation and energy release can be accurately controlled. Thus the range of instruments can be properly set, and all instruments can be calibrated before and after the explosion. The travel-time curves then can reveal more detailed information about the structure of the earth because source uncertainties are removed. In addition since the sources can be placed anywhere, the seismologist need not rely only on signals from active seismic areas.

A source fired in the Antarctic, which is an aseismic region, would reveal valuable information. Press and Griggs (*21*) have indicated that a nuclear detonation deep in the ice (deep enough to prevent release of radioactivity to the atmosphere) would yield data on the average distribution and thickness of ice, distribution of land mass under the ice, and crustal thickness information. For a sufficiently large shot (100 kt), strong signals would be received all over the world and information on inner and outer core, and other structural details could be resolved. This experiment should be done and should be conducted as an international experiment in the traditions of the IGY and of seismology.

All Plowshare nuclear shots, wherever they are fired, will be announced well ahead of time and fired at specified published times so that the seismic scientific community will be able to take full advantage of the signal.

Nuclear Cross Sections

The enormous neutron flux intensity generated during a nuclear explosion can be used to improve our knowledge of neutron cross sections and fission processes by orders of magnitude. The accompanying article by D. J. Hughes on p. 54 explains how explosions can be used for this purpose and describes the experiments planned for Project Gnome.

contain a quantity of oil approximately equal to the world's proven reserves. Because of the high viscosity of the oil and the approximate 1,000 ft of overburden, all attempts to extract the oil from the formation economically have failed. Heating the tar sand to 100° C lowers the viscosity of the oil enough so that it may be possible to pump the oil from the sand. In the experiment a 9-kt nuclear explosive detonated immediately beneath the tar sand formation will heat the adjacent tar sand and fracture the interbedded layers of shale, thereby permitting study of the problems of recovery of the trapped oil. In addition to the direct heating mechanism some oil also may be rendered recoverable by shock heating. Furthermore, the possibility of further recovery by secondary processes can be examined.

The planned detonation, approximately 20 ft below the base of the tar sand formation, will produce a cavity about 250 ft in diameter which will subsequently collapse. When collapse occurs the fractured tar sand and shale formation will tumble into the cavity and be heated by the energy which was deposited locally by the explosion. With a temperature distribution in the collapsed zone like that of the Rainier shot an estimated 100,000 barrels of oil might be recoverable from a 9-kt explosion. Based on experience in tuff in Nevada, no cratering, surface subsidence or breakthrough is expected. Ground-water movements in the proposed area have been thoroughly studied and it was concluded by the Alberta and Ottawa technical committees that there will be no groundwater contamination problem.

On approval by the Canadian authorities and the AEC, Project Oil Sand could be conducted 6 months from the time authority to proceed is obtained.

Project Chariot

Project Chariot is a nuclear excavation experiment to be done at a point on the northwest coast of Alaska near Cape Thompson (Fig. 4). It will demonstrate the capabilities of nuclear explosives for excavation projects with greatly reduced release of radioactivity to the atmosphere—a necessary step before earth-moving projects near populated regions can proceed. These projects may eventually include excavations for harbors, canals, strip mining (7) or flood control reservoirs.

As presently planned, four 20-kt and one 200-kt nuclear explosives buried at optimum depths for cratering and containment of radioactivity will be simultaneously detonated to produce a single crater which, if desired, will serve as a small harbor.

The only reliable nuclear cratering data presently available are for 1.2-kt explosions in alluvial fill at the Nevada Test Site. Project Chariot has been designed to extend this knowledge to yields more consistent with useful excavation projects and to gain experience in a harder medium than alluvium. In addition, Chariot will give important data on the gains to be realized by the simultaneous detonation of a line of nuclear explosives.

The amount of radioactivity released to the atmosphere by a nuclear cratering detonation varies strongly with the depth of burst. A 115-ton explosion (Neptune) (8) in Nevada indicated that the depth can be adjusted to excavate almost a maximum volume with only 1–2% of the gross radioactivity escaping to the air. In Project Chariot, which will use similar scaled depths of burial, plans call for measurements of the distribution of radioactivity in the "fallback" material in the crater, on the surface in the vicinity of the crater, on the surface within 100 miles and in the atmosphere.

A thorough survey of biological and ecological effects is being made under the auspices of the Division of Biology and Medicine. The biological program will provide information to adjust factors such as time of year and direction of fallout to minimize biological cost.

* * *

The work summarized here was the result of efforts by many individuals in the Plowshare program from several laboratories. Many helpful criticisms and suggestions were made of the manuscript by the late Donald J. Hughes, Brookhaven National Laboratory, and Roger E. Batzel, Lawrence Radiation Laboratory. Material was drawn freely from the reports of the Second Plowshare Symposium conducted in San Francisco on May 13–15, 1959.

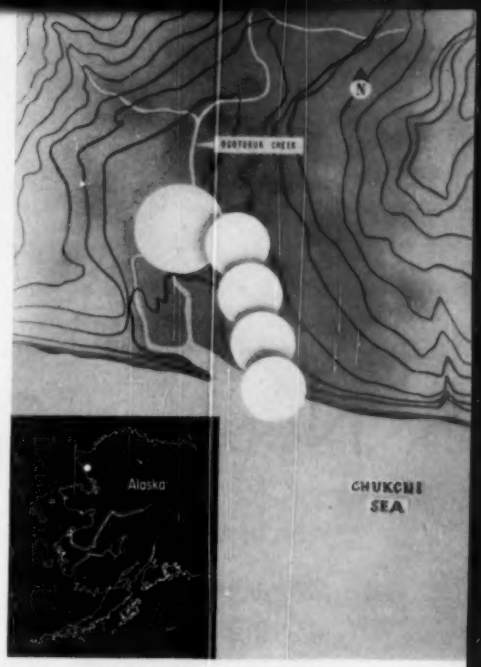

FIG. 4. PROJECT CHARIOT will use 5 simultaneous nuclear explosions to blast out small experimental harbor in Alaska

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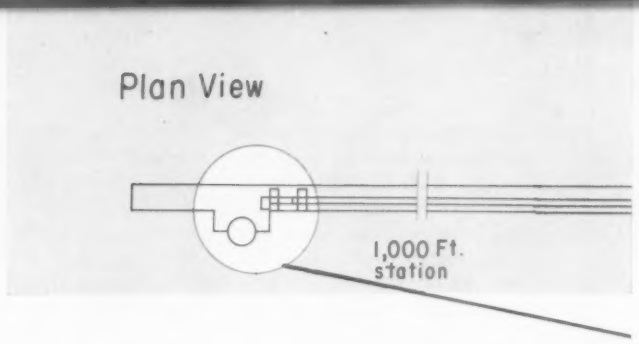


Neutron Spectroscopy with Nuclear Explosions

A research reactor would have to operate for thousands of years to produce as many neutrons as a single nuclear explosion. Experiments designed around this enormous source intensity could improve by an order of magnitude our knowledge of resonance cross sections

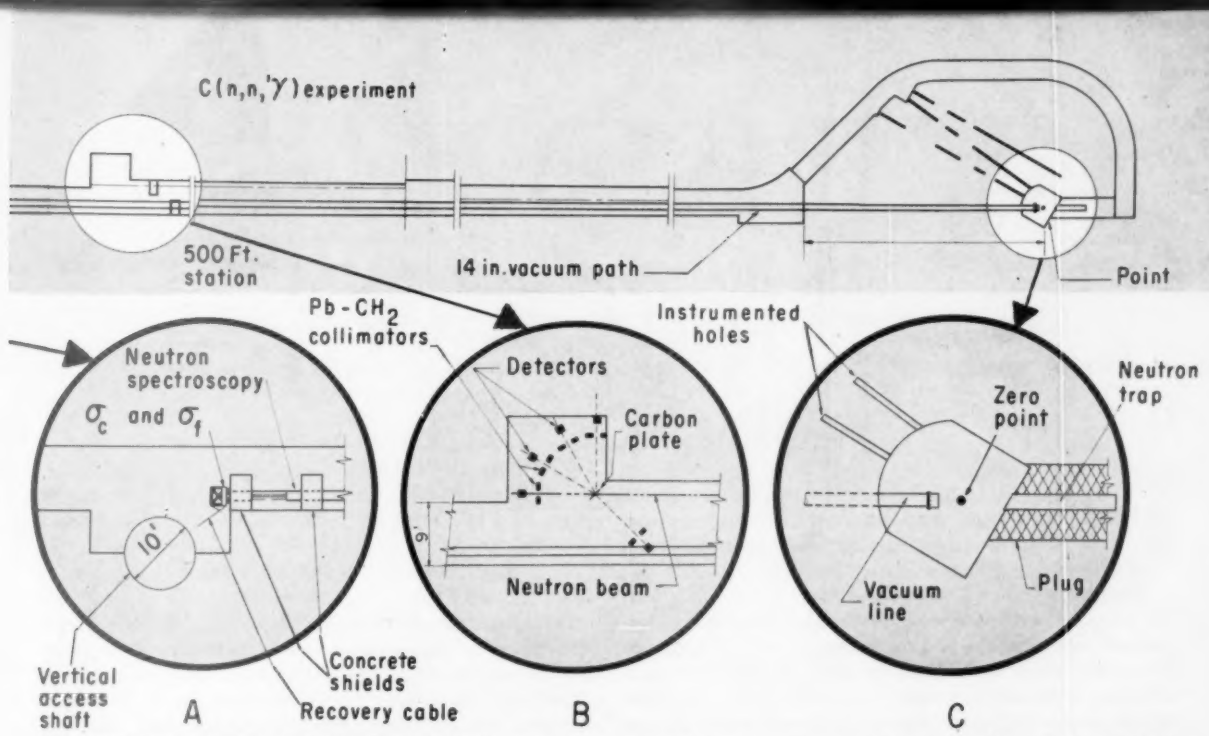
The field of high-resolution neutron spectroscopy has advanced rapidly in the last decade and has produced much data of value to nuclear-structure theory. It is fortunate that, in addition, the experimental results—neutron cross sections in the resonance energy region—have great practical utility in the design and understanding of nuclear reactors. In the present report I would like to consider the possibility of pushing neutron spectroscopy even further by exploiting the nuclear explosion as a neutron source.

Neutron Spectroscopy

Let us first look briefly at what the field is all about, and then go into the matter of what we can do with the nuclear explosions; perhaps you will then share my enthusiasm for their use as a source for neutron spectroscopy. The results of neutron spectroscopy measurements, consisting of neutron-resonance parameters, furnish a detailed view of the energy levels in a very narrow region of excitation energy of the compound nucleus for a large number of nuclei. Most of the results have come from nuclei with mass numbers greater than 80 or so, simply because these nuclei usually have closely spaced levels in the neutron-energy range where the instruments have high resolution. The region of excitation energy that we are here considering is slightly above the neutron binding energy, hence above 5–8 Mev, where the level spacing is typically a few volts. Thus

Dr. Donald J. Hughes, the author of the accompanying article, died suddenly on April 12, 1960, at the age of 45 of a coronary thrombosis that first occurred the week before. Don Hughes was one of the pioneers in the development of the U. S. atomic energy program, having joined the Manhattan Project in 1942. He was among the small group of physicists that put into operation the first plutonium-producing reactor at Hanford. After the war he became chairman of the physics department at Argonne National Laboratory. Among his many contributions there were the first accurate measurements of the delayed neutron groups from fission and measurements of resonance neutron absorption and the neutron-proton interaction.

In 1950 Hughes joined Brookhaven National Laboratory to devote full time to research. Here his work with fast chopper techniques provided the basic data for our present day understanding of resonance-neutron interactions and his search for an empirical understanding of these phenomena led to the compilation of the now famous BNL-325. In recent years his interest in neutron physics has ranged from interactions of the lowest energy (10^{-3} ev) to those of the highest energy (10^{9} ev). His understanding and insight into the problems of neutron physics will be sorely missed.—H. Palevsky, Brookhaven National Laboratory.



NEUTRON EXPERIMENTS FOR PROJECT GNOME. View from above of horizontal tunnel for Project Gnome (see p. 51) shows arrangement of cross section experiments that will use neutron burst from 10-kt explosion. Neutrons that enter 1,000 ft vacuum pipe at C are detected at A by electronic time-of-flight circuits which will measure resonance transmission for U^{233}, U^{235}, U^{238} and Pu^{239}. Originally planned by author, this experiment will improve resolution of resonances by factor of four over present data. Two rotating target wheels (see Fig. 3) also located at A will measure fission properties of U^{238} (with 0.1-ev resolution up to 1 kev) and capture cross sections for several isotopes including Th^{232}, W^{184}, W^{186}, Ta^{181}, Hf^{180} and Au^{197}. At B, Cerenkov detectors will measure angular distribution of 4.4-Mev gammas from C(n,n',γ) reaction. Resolution will be 0.1–0.3 Mev for 4.8–15 Mev neutrons

at this energy there is a small band, say one kev wide, where there are many levels that we can study with really high accuracy. The energy band is this narrow because resolving power rapidly decreases above one kev.

The energy levels appear as resonances in the measured cross section, plotted as a function of neutron energy. Each resonance represents an energy level at some 5–8 Mev excitation, although the corresponding neutron energy is only a few ev. It is an interesting and useful fact that the total cross section alone, which is the easiest type to measure, gives a lot of information about the energy levels. For example, Γ the total level width (which gives the lifetime of the excited state) is given simply by the measured width of the resonance in electron volts. The excited state can decay by emitting a neutron, various combinations of gamma rays, and in some cases by fissioning or emitting protons or alpha particles. All of these modes have corresponding partial widths, which can be measured—the neutron width, the gamma width, which is in turn made up of many partial gamma ray widths, a fission width, and so on.

It is also possible to investigate the spacing of the levels, both the average spacing for various nuclides and the matter of how the spacings are distributed within a single nuclide, whether at random or with some regularity. Finally there is the spin of the level, J, which also is now being measured by methods of neutron spectroscopy. All of these results obviously have a close connection with nuclear theory and they have been of great value in the development of such theory, primarily with regard to nuclear models.

High Resolution

The problem of getting good data is primarily one of developing a neutron source of high resolving power. The

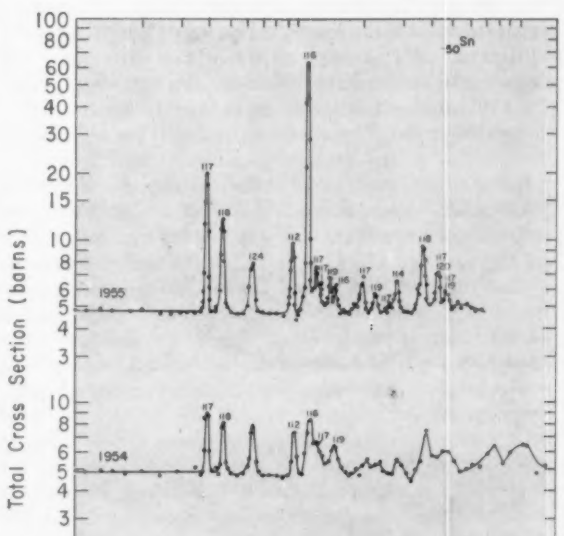


FIG. 1. RESONANCE-DATA EVOLUTION. Measured cross section of tin from various editions of BNL-325. Curves show increase in number and size of resonances with increased resolving power

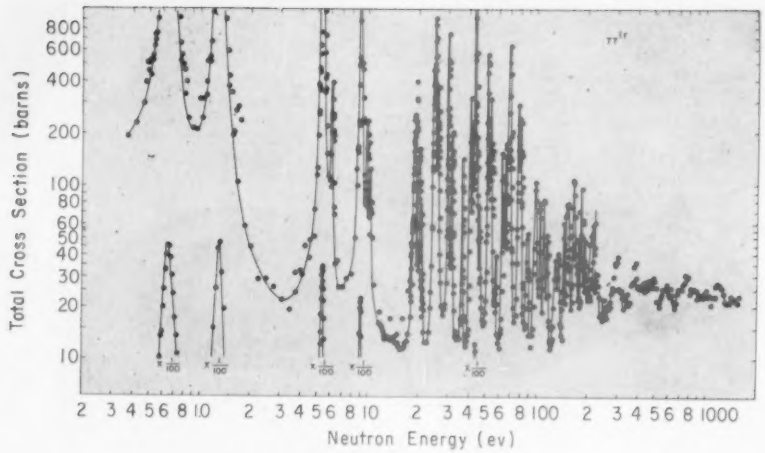


FIG. 2. ROOM FOR IMPROVEMENT. Total cross section of iridium, measured recently with the Brookhaven fast chopper, shows unresolved resonances above 100 ev

best way to describe the progress and present status of high resolution instruments is to examine some representative data in the neutron spectroscopy field. Figure 1 shows a surprising change of cross sections with time. The cross section of tin in 1952 (the dates refer to successive editions of BNL-325) appeared structureless, and at the time this behavior seemed reasonable because the tin nucleus contains 50 protons, and 50 is a magic number. However, the truth is that magic numbers have nothing to do with the results. In 1954 some resonances started to appear; in 1955 they were much more prominent, there were many more of them, and we even knew to which isotopes of tin they belonged. Were we to include a 1960 curve (not available as yet), we would see that the low energy region would hardly change at all, but at higher energy we would now have more and sharper resonances. So as resolution gets better and better, the information gets better—but we must be careful at each stage that the information we give to theoreticians is trustworthy, so that we in turn can trust their theory.

Some recent work done at Brookhaven on iridium is given in Fig. 2, as an example of typical resonance structure as the neutron energy increases up to a few hundred ev. At low energy, say up to 30 ev in Fig. 2, the resolving power is sufficiently good that we get the kind of information just described directly from the cross section curves. But as we get into the upper end of Fig. 2, we obviously can't resolve all the levels—the thing that is needed to get more and better data in this field is simply higher neutron-energy resolving power.

Of the instruments that have been used in neutron spectroscopy, the most prolific in data production this far has been the "fast chopper," a mechanical shutter used with reactors. A fast chopper of Brookhaven design was installed about a year ago at the new NRU reactor at Chalk River, which has a central (thermal) flux of about 2×10^{14}. The fast chopper, essentially a heavy rotor 1 m in diam contained in an evacuated case, is placed at a beam hole that passes into the center of the reactor. The neutrons are chopped into bursts as the chopper spins; each burst lasts one microsecond, about the shortest burst that can be obtained by these mechanical devices. The chopped beam then travels through a helium-filled balloon that extends out of the reactor building to a point about 200 meters away on the bank of the Ottawa River.

In resonance analysis the resolving power is always stated in terms of microseconds per meter, or the uncertainty in time in microseconds. In a device like this the resolving power would be about a microsecond, divided by the length of flight. If we have a 100-m flight path the resolving power would then be 0.01 μsec/m. The spread in energy corresponding to this resolution would be 0.01 ev at 10 ev, and 10 ev at 1 kev. This resolution is sufficiently good to analyze some twenty resonances or so in typical materials; better resolution is obviously needed.

The pulsed machines are about comparable to fast choppers in resolving power at the present time. As an example, a resolution of 0.01 μsec/m has been obtained with the Columbia synchro-cyclotron. Linear accelerators recently have been doing very well also, with regard to resolution and intensity as well. One of the best is the French accelerator at Saclay, which produces pulses of about 1 μsec with a neutron emission rate of about 10^{15} neutrons per second during the burst. A recent fission cross-section measurement of U^{235} with this instrument is definitely superior to previous results.

Nuclear-Explosion Source

Now let us consider how a nuclear explosion compares as a source for neutron spectroscopy with the fast chopper at the NRU or a typical pulsed source. First, let us examine the neutron intensity available from our explosion and compare it with a pulsed source. To make things international, we can talk about the high-power pulsed source now being built by Soviet scientists at Dubno near Moscow. This is a pulsed source that isn't out of this world by any means, but is designed for an extremely high intensity—10^{17} neutrons/sec during a 10 μsec burst. Actually it is a "pulsed reactor," similar to several already used at Los Alamos. But the designers of the Soviet machine hope to have a high repetition rate, in addition to the intense neutron emission during the burst. The period would perhaps be something like $\frac{1}{10}$ of a second. These figures would give 10^{12} neutrons per burst or 3×10^{20} per year of continuous operation.

Now it is easy to compare this source with a nuclear explosion, for the pulsed reactor would need a moderator neal or around it, and so would the nuclear explosion to produce resonance energy neutrons. The simplest way in principre

to use the nuclear explosion for high-resolution neutron spectroscopy would be to place a moderator near it and to time the flight of the neutrons down a 1-km vacuum pipe to a detector. For this arrangement, we can compare directly the 3×10^{20} neutrons per year emitted by the pulsed reactor with a nuclear explosion which could give of the order of 10^{24} emitted neutrons. From these admittedly approximate numbers, we conclude that one shot is equivalent to the operation of the Russian pulsed reactor for 3,000 years! We can understand why people in the neutron spectroscopy business might feel that a nuclear explosion is a potent thing.

Let us now turn to a comparison of the explosion with the other velocity selector, the fast chopper at the NRU, which gives a very high intensity for this type of neutron spectrometer. For the experimental arrangement of the explosion we can assume that a few meters from the explosion we have a slab of appropriate moderator about a meter square. The slab can't be too thick because we don't want to introduce too much uncertainty in timing; so we shall be conservative and make it so thin that only 10% of the incident neutrons get moderated in it, the others escaping. Then 100 meters away we place the neutron detector with timing circuitry and the samples whose cross sections we desire to measure. Under these conditions and starting with 10^{24} emitted neutrons, we can compute the number in a given energy range incident on the detector. The result is 4×10^{10} neutrons/cm^2 in a 1 ev energy interval about 10 ev for one explosion. For comparison with this result, we have the intensities that we are actually getting for the fast chopper at the NRU reactor at the present time. There we have a certain counting rate which, converted to 24 hours a day for a year, gives a figure of 10^7 neutrons/cm^2 in the same energy interval just considered. So strangly enough we end up with about the same factor as we did for the pulsed reactor—one shot is the equivalent to the operation of the fast chopper for a few thousand years.

Recording Equipment

Upon seeing figures such as those we have just computed, the usual reaction of one versed in the high-resolution neutron field is, "How can we use all this intensity in such a short time?" Well, outside of the difficulty of planning your experimental program for the next 3,000 years there are other difficulties too. Fortunately they are not really so bad as one's immediate reaction would indicate. There is no real trouble in getting the neutrons out of the exploding material on time and so on. True, they are much slower than the ones that people usually are concerned with when working with nuclear explosions. Nevertheless, they still are well in advance of the shock wave so that they can get out and data can be recorded before the instruments are damaged. Actually the recording equipment would be far enough away from the explosion so that it would be unharmed.

The information that must be recorded is rather complicated, as shown by the typical data of Fig. 2. The way in which these data are handled in the neutron spectrometers requires rather complex thousand-channel time analyzers, and the big problem is to store the data in the machine perhaps for days. For this purpose various storage devices such as ferrite cores, magnetic drums or electrostatic tubes are used at present. In one way the recording of data for a nuclear explosion is much simpler because it is not necessary to keep the data in the machine for days. It is obtained al at once and by recording current in the neutron detector not counts. The information would be recorded by photos of oscilloscope patterns. The people who have done this have convinced me that the kind of detail that would be observed in time-of-flight experiments can certainly be recorded. Thus I feel that recording data—the time analysis and the storage of intensities in thousands of channels—is actually easier for the explosion than it now is for conventional methods.

Possible Experiments

The second difficulty arises when we consider the various types of experiments that can be done. The usual experiment is simply a transmission measurement in which the intensity with no sample is recorded then the intensity with the sample in the beam. There is no reason why an experiment of this type can't be done with a nuclear explosion in exactly the same way although we would obviously use two calibrated detectors, one with and one without a sample. The more complicated experiments concern partial cross sections where, instead of a simple neutron detector for sample transmissions, more complicated measurements are made. For instance, a scattering experiment is one in which we have some sort of neutron detector near the sample, in which we measure the intensity of the scattered neutrons as a function of time and, perhaps, of scattering angle as well. Other possible experiments are ones in which a gamma ray detector would be used to study the capture cross sections or fast neutron detectors to measure fission cross sections. These partial cross sections although more difficult than the total cross section can all be measured in the same way by using the correct instrument and recording current. Cowan, working at Los Alamos, has already used a nuclear explosion to study fission properties (Fig. 3). By activating U^{235} mounted on a wheel rotating in a beam of neutrons from the explosion and performing a subsequent radiochemical analysis, he was able to measure the yields of various fission products in different neutron resonances.

There are one or two experiments that cannot be performed, however, at least in precisely the ways that are now being done. One is an experiment that is currently receiving a lot of attention—the study of the individual gamma rays following neutron capture. Experiments are now under way in which the relative intensities of a particular gamma ray, for example the ground state transition, are measured in the different resonances. The results show how transition probabilities to a particular final state vary from different initial states. At the present time, these measurements are made by analysis of pulse-height in scintillation crystals, combined with time analysis, to identify respectively gamma ray and neutron energy. The simple pulse-height analysis is obviously impossible when current is recorded, but I am sure that experiments of this type can still be done by using another and better type of energy measurement, involving magnetic analysis for example. Another type of experiment definitely not feasible with nuclear explosions is the one in which we measure coincidences to study the decay scheme of the capture gammas in detail. But with the exception of coincidence measurements, all the standard experiments can be done as well as others not now possible.

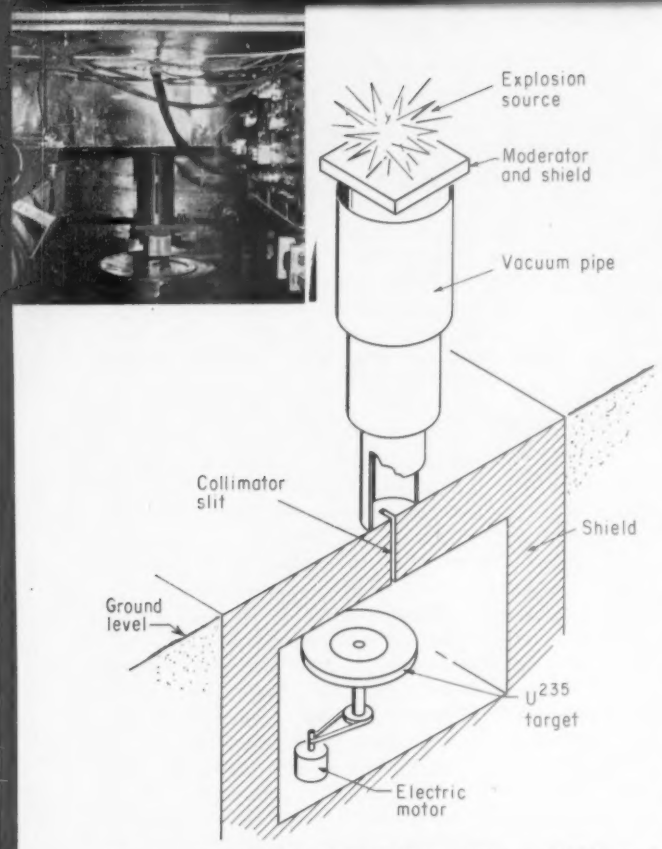


FIG. 3. LOS ALAMOS EXPERIMENT in October of 1958 used neutron pulse from small nuclear explosion to bombard target wheel rotating at high speed 100 ft away. In this arrangement neutron velocity has direct relation to position at which neutron strikes target rim, giving an energy resolution of a few per cent between 10 and 100 ev. Insert shows photograph of actual experiment before burst

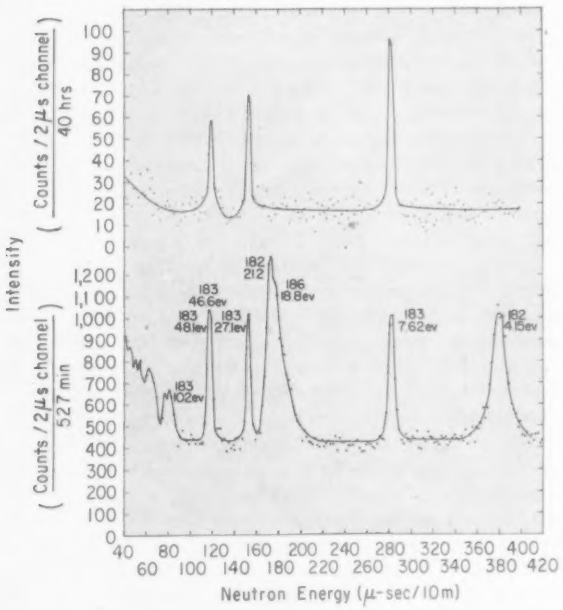


FIG. 4. GAMMA RAYS from various resonances in tungsten. Upper curve is ground-state intensity and lower curve is intensity of low-energy gammas. Resonance levels that appear in upper curve are from W^{184} and have spin $J = 1$

Should the high intensity of a nuclear explosion become available, I think the first job anyone in this field would want to put on the experimental program would be a really complete analysis of U^{233}, U^{235} and Pu^{239} in the resonance region. This analysis would mean measurements of total cross section, fission cross section, fission fragments and so on. These measurements are all of the type that can be done now with conventional neutron spectrometers but relatively so poorly that nuclear explosion results would constitute a completely different order of magnitude in accuracy. Another possible experiment would be the detailed study of neutron capture, not only in resonance levels but between levels as well. This latter is essentially the type of measurement that can't be done at all with present techniques.

To understand the need for high source intensity for neutron spectroscopy, let us consider briefly the counting rates typical of the gamma-ray experiment just mentioned. In this particular case the compound nucleus is W^{184} and there is a ground-state gamma ray of 7.4 Mev, as well as a transition to the 2^+ state about 100 kev away. The advantage of this state of affairs is that it is possible to identify the spins of the levels; if we find the ground state gamma* the level has $J = 1$ because this gamma cannot be emitted for levels of the other possible spin $J = 0$. In this way the spins can be determined for the various levels corresponding to the neutron resonances in the target nucleus W^{183}. A pulse-height analysis shows that the ground-state gamma is down in intensity by a factor of about 1,000 relative to the low-energy gamma rays. The experiment consists in measuring the intensity of the high-energy gamma ray from level to level and it is not surprising that the counting rate is so low.

An example of results obtained at Brookhaven is shown in Fig. 4. Fortunately we have now gained a factor of about 80 in intensity by moving to Chalk River. We have here an analysis in terms of time-of-flight (or neutron energy) and gamma energy as well. The time-of-flight results for a low bias setting on the crystal represents low energy gammas and the high bias setting responds only to the ground state gamma in W^{184}. Some of these levels appearing at low bias are known to be in the target isotopes W^{182} and W^{186}, but, as they have low binding energies, the levels disappear completely at high bias. The resonance levels in the target nucleus W^{183} that appear at high bias, such as those at about 8 and 27 ev, are thereby shown to be $J = 1$ levels. At about 48 ev there are two levels we can't resolve, and together they appear at high bias, but weakly. We have since found out by running at high resolution at Chalk River that one of these levels is $J = 0$ and the other is $J = 1$, thus explaining the results of Fig. 4. However, we are not interested here in the reporting of nuclear physics, but in emphasizing the need for increased neutron intensity. The ordinate in Fig. 4 is counts per channel in 40 hours and rates run about 40. In other words, we get about one count an hour, with a background of a count every 2 hours!

I think it is quite obvious from such counting rates that if someone would guarantee that we would have about two of these explosions a year available as neutron sources, we would gladly pack up our equipment, move out, and start planning measurements.

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* Actually, transitions to the 111 kev level are included, but these behave similarly to the ground state transitions, and no uncertainty results.

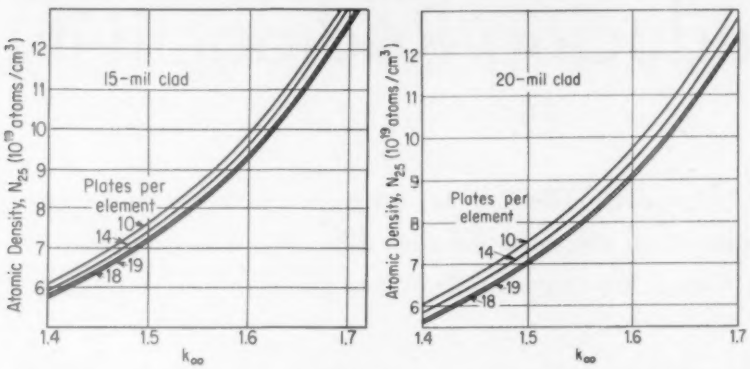

FIG. 1. k_∞ as a function of U^{235} atom density in fuel section of MTR-type elements. Curves (a) refer to elements with 15-mil Al clad and curves (b) to 20-mil clad

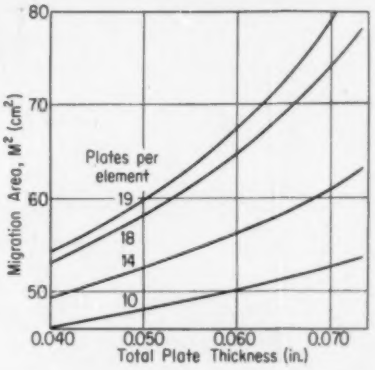

FIG. 2. Migration area M^2 vs. total fuel-plate thickness (including cladding thickness)

Criticality of MTR-Type Fuel Elements

By ROBERT E. LIGHTLE,* *The Babcock & Wilcox Co., Lynchburg, Virginia*

A SIMPLE GRAPHICAL METHOD can be used to predict the criticality of water-reflected MTR-type fuel elements. The method gives k_{eff} of a critical or nearly critical core to within 4% of the measured value and has been found useful for quick survey work.

The basic assumption is that the criticality of a parallel-plate core can be predicted by the simple formula

$$k_{eff} = k_\infty/(1 + M^2B^2) \qquad (1)$$

The infinite multiplication factor k_∞ is a function of the number density of U^{235} (atoms/cm^3), the number of fuel plates per standard fuel element, and the aluminum cladding thickness of the fuel plates. Figures 1a and 1b give k_∞ vs. U^{235} atom density with the number of plates as a parameter for 15-mil and 20-mil cladding thicknesses respectively. (The 5-mil variation in cladding produces only about 0.3% difference in k_∞.) The U^{235} atom density N_{25} (in units of atoms/cm^3 $\times$ 10^{-24}) is

$$N_{25} = \frac{\text{total gm } U^{235}}{N} \times 0.6975 \times 10^{-6} \qquad (2)$$

where N is the total number of fuel elements of all types in the core.

The second quantity on the right of Eq. 1, migration area M^2, is given in Fig. 2 as a function of the number of fuel plates per element and the plate thickness. M^2 is the sum of a Fermi age and a thermal diffusion area.

The buckling B^2, more difficult to present simply, is assumed to follow the relationship

$$B^2\ (\text{cm}^{-2}) = \left(\frac{2.405}{r + \delta}\right)^2 + 0.00177 \qquad (3)$$

where δ is the radial reflector savings and r is the radius of the configuration. We determine r by the equation

$$r\ (\text{cm}) = 15.68\ N/N_p \qquad (4)$$

where N is the number of elements in the core and N_p is the number of element sides forming the perimeter of the core assembly. The radial reflector savings δ is given in the table.

The method is known to be valid for a solidly constructed core—one in which no elements have been omitted from the center of the array. This holds even for somewhat irregular arrays and for cores with one or two elements outside a square array. The validity *has not* been verified for cores that have large water volumes enclosed within the core.

Reflector Savings δ (cm)

Enrichment	*Plates per element* 10	14	18–19
93% ($N_p \leq N$)	6.7	7.7	8.7
93% ($N_p > N$)	8.3	9.3	10.3
20%	7.5	7.6	7.7

Sample Calculation

To demonstrate the simplicity of the method, we will calculate k_{eff} for the operating core of the Lynchburg Pool Reactor. This core has a 4 by 4 array of parallel-plate elements with 10-plate standard elements. Each plate has a 20-mil meat thickness with a 15-mil aluminum clad on each side. The total loading is 2,622 gm of fully enriched U^{235}.

In this arrangement, $N = 16$, $N_p = 16$, and $N_{25} = 0.000114$. From Fig. 1, $k_\infty = 1.650$. From Fig. 2, $M^2 = 48.15$. In the B^2 equation $r = 15.68$, and from the table $\delta = 6.7$; thus, $B^2 = 0.0133$.

Substituting these values in Eq. 1,

$$k_{eff} = \frac{1.650}{1 + (48.15)(0.0133)} = 1.0058$$

The measured value at the reactor was 1.0064 ± 0.001. Experimental checks of method against many other critical cores have given results of similar accuracy.

We have shown in the example how to calculate k_{eff} but any of the other parameters could be found by assuming a particular k_{eff} value.

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Reducing Radioactivity

Buildup of long-lived radionuclides on primary-system surfaces can make operation and maintenance difficult. SM-1 experience indicates some design considerations that could minimize buildup

By WILLIAM S. BROWN and CARL A. BERGMANN, *Alco Products, Inc., Schenectady, New York*

BUILDUP OF LONG-LIVED gamma activity in the primary coolant system has been studied in many pressurized-water reactors (*1*). The main concern is with neutron activation of reactor structural materials and transport of the activity through the primary system—not with fission-product release by defected fuel elements. In particular, measurements in the SM-1 (formerly APPR-1), the Army Package Power Reactor, are useful for indicating the mechanisms of activity buildup, the effect on reactor operation and aspects of system design that should be considered for minimizing buildup.

Major factors participating in the buildup process are corrosion of primary-system materials and corrosion-product deposition. (After extended reactor operation, radionuclides suspended or dissolved in the coolant contribute relatively little to the activity levels in comparison with surface deposits.) Transport mechanisms probably introduce crud from several sources and remove it to several sinks simultaneously. Sources of activity include corrosion-product release from in-flux components and activation of crud deposits in high-flux regions and corrosion products in the circulating coolant. Crud sinks include the purification system, crud traps and the out-of-flux surfaces of the system.

On the basis of these mechanisms, the degree of activity buildup is a function of several parameters (Fig. 1): the extent of corrosion of primary-system materials, nuclear characteristics of core and structural materials, coolant chemistry, primary-system geometry, and transport and deposition mechanisms. The extent to which each parameter affects activity buildup is unknown, which makes the prediction of radiation levels in the primary system difficult.

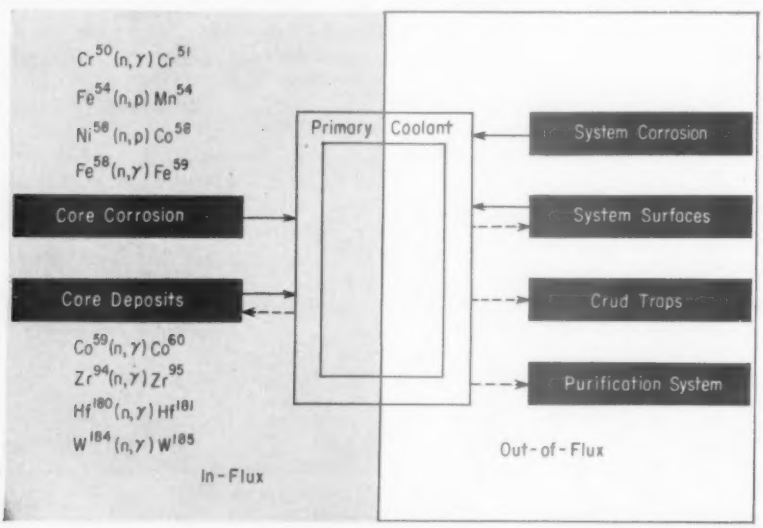

FIG. 1. SOURCES AND SINKS of radioactivity buildup in pressurized-water reactor. Neutron activation can produce radioactive nuclides in the core, which are then released to primary coolant by corrosion; out-of-core corrosion products are transported to in-flux region and then activated. Radioactive coolant impurities from all sources are deposited throughout primary system

The radiation level on primary-system surfaces is proportional to (a) the specific activity of the nuclides in the corrosion-product film and (b) the film thickness. The film thickness, in turn, is related to the amount of corrosion of the primary system and the transport, deposition and erosion of the corrosion products. The specific activity of the crud depends on such parameters as the relative amounts and half-lives of the radionuclides.

The SM-1 differs from other operating pressurized-water reactors in that the entire primary system, including fuel cladding, consists of type 304 stainless steel. Thus, the major long-lived, gamma-emitting nuclides are Cr^{51}, Mn^{54}, Co^{58}, Fe^{59}, and Co^{60} (*2*). In a zirconium-containing reactor, such as Shippingport, Zr^{95} and Hf^{181} would also be present (*3*). Our discussion is based on a stainless-steel system.

After 17 months of SM-1 operation, a 50–83-mg/dm² corrosion-product film was deposited on primary-system surfaces. Radiation levels external to the piping due to this radioactive film were 60–70 mr/hr 24 hr after shutdown. Higher radiation levels occurred where crud collected in stagnant or low-flow areas. After two years of operation, Co^{60} and Co^{58} accounted for ~80% of the long-lived gamma activity (Fig. 2).

Buildup in PWR's

Buildup Mechanisms

Mathematical equations have been derived by several investigators to describe the over-all activity-buildup process. Because of the complexity of the process and mathematical difficulties, simplifying assumptions have been made when considering the mechanisms in a particular reactor. These are discussed in detail later in this article.

Recently, Yerazunis *et al.* (*4*) proposed a comprehensive multiple-mechanism theory of system activation. The theory includes the concept of activity transport by molecular diffusion as well as by particulate exchange between permanent and transient layers of the crud film (permanent layers are adherent, and transient layers are susceptible to coolant erosion). The differential equations describing the multiple activation process have been coded for digital-computer solution. Comparison of measured and calculated activities from in-pile loop tests and the S3G reactor supports the theory.

The contribution of each activity source to the total system activity depends on the location and composition of the reactor materials. For example, in the SM-1 $\sim 75\%$ of the cobalt is located in the high-flux areas, which is accounted for by the Haynes-25-alloy neutron-flux suppressors and the cobalt impurity in the stainless steel. For this reason, the major source of Co^{60} is assumed to be the release of activated corrosion products in the in-flux areas. Cobalt-60 buildup calculated on this basis agrees with the measured buildup. On the other hand, for plants that have a relatively small proportion of in-core stainless-steel surfaces (such as the Naval reactors), the measured levels of Co^{60} cannot be accounted for solely by the activation of the in-flux stainless steel components. For this reactor type, calculations have confirmed that corrosion products transported to the in-flux areas are the major source of Co^{60}. The difference in the major activity sources of the different reactor types does not necessarily imply that the same activation mechanisms are not being followed. Thus, in the SM-1, the contribution of Co^{60} by out-of-flux corrosion products is probably masked by that from the in-flux surfaces.

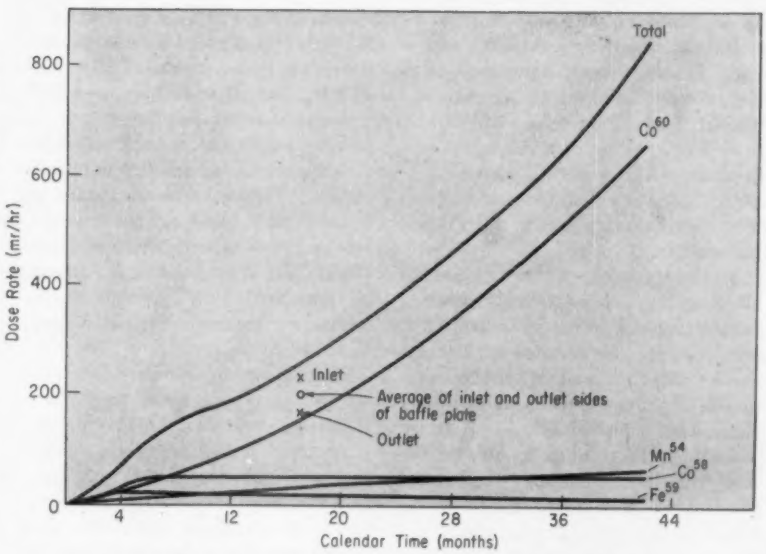

FIG. 2. BUILDUP of principal nuclides in SM-1 primary-system deposits

Buildup Calculations

Early mathematical models proposed to describe induced activity buildup were based on simplifying assumptions. It was assumed that most of the total system activity was activated corrosion products released from in-core surfaces. One model assumed that all activated corrosion products deposit on the primary-system surfaces (*5*). Others included the loss of nuclides to the purification system (*6*), the effects of recoil and crud activation while circulating through the core (*7, 8*) and the re-release of crud from the system walls (*9*). Calculations based on a constant weight of deposited crud film and its relationship to the activity of the waterborne crud also have been reported (*10*).

Later models included the activation of out-of-core corrosion products that deposit on in-flux surfaces (*4, 11*).

Mathematical equations have been derived to describe the activity buildup in the SM-1 (*2*). Assumptions used in the derivation and numerical values for constants in the equation were based on experimental data. As shown in Fig. 3, Co^{60} becomes the significant contributor to total dose rate after about 12 months of reactor operation. The calculated dose rates on the primary-system walls show good agreement with those observed on the steam-generator baffle plate. Theory for buildup of Co^{58}, Mn^{54} and Co^{60} also agree well with the observations on metal test specimens exposed to the coolant.

The mathematical expressions used to calculate activity buildup have certain limitations:

1. Chemical-radiochemical data are required to evaluate certain constants or coefficients used in the equations. Constants obtained for one reactor, however, may not be applicable for accurate prediction of activity buildup in another reactor system.

2. Reported (n,p) cross sections (for production of Mn^{54} and Co^{58}) vary by a factor of four; for precise results, the product of cross section and flux $(\sigma\phi)$ should be experimentally determined

for the reactor being considered.

3. It is inaccurate to assume a constant corrosion-product release rate. Based on experimental data from the SM-1 (*2*), the release rate of 304 stainless steel, under SM-1 operating conditions, apparently is not constant. In a long-term analysis, it may be valid to assume a constant release rate; however, good agreement with data obtained early in the operation of a reactor would not be expected.

4. The validity of assuming a constant deposition probability is questionable. Experimental evidence indicates that the deposition rate in the SM-1 is not steady (*2*).

5. The equations do not consider the effect of reactor design and operating parameters, e.g., primary coolant flow, temperature and chemistry. For example, SM-1 surfaces exposed to water at 430° F showed greater activity than those exposed at 120° F. Activity levels have been found greater on the inlet surfaces than on the outlet surfaces of the steam generator in SM-1 (*2*) and S3G (*4*); this effect may be due to the temperature difference, heat-transfer effects, variation in crud concentrations through the steam generator or other factors. Coolant chemistry also would be expected to affect activity buildup. Corrosion product release rates of metals at different *p*H would be expected to vary, and the adherence of deposits at various *p*H values might be different.

6. Existing methods for calculating radiation levels for complex geometries are not adequate. For example, calculated dose rates at the tube sheet of the SM-1 steam generator were a factor of five lower than the observed values due to the complex geometry of the steam generator and inaccuracy of available equations.

Effects on SM-1 Operation

After nearly two years of operation of SM-1, radiation levels at the inside entrance of the vapor container 24 hr after shutdown are approximately 40 mr/hr. Although certain "hot spots" have increased to 2.5 r/hr, maintenance activities have not been seriously hindered. Several special research and maintenance activities, however, have needed careful planning to avoid overexposure to personnel. No one has received a dose beyond the limits set by the AEC.

Effect on research. The greatest personnel exposures from primary-system components occurred when measuring the short-lived activity immediately after reactor shutdown. After a year of reactor operation, doses to personnel were checked frequently to assure that 50 mr/day was not exceeded. Since immediate access to the primary system for maintenance has not been required, short-lived activity has not so far been a problem.

Metal test samples inserted in the primary purification line provided data on accumulation of activity on different metals. Proximity to crud traps and a crud filter has hindered somewhat removal of sample holders. Local shielding with lead sheets and rotation of personnel have precluded overexposure when removing and replacing these specimens.

Effect on maintenance. Several instances have illustrated the effect of radiation levels on SM-1 maintenance.

At times it was necessary to shield the pressurizer-line elbow with $\frac{1}{16}$-in. lead sheets while working on a thermocouple assembly on the steam-generator inlet pipe, about 4 ft from the elbow. When water was drained from the primary system, dose rates at the elbow (2 r/hr) decreased significantly —apparently this displaced accumulated crud from the elbow.

After 1½ years of reactor operation, the steam-generator water box and tube sheet were inspected (*12*). The anticipated high radiation levels required careful planning. To make the inspection, as well as obtain research and development data, 48 men spent 673 manhours. It is difficult to estimate the time necessary for tube or tube-sheet repairs. The time to remove and reapply the steam generator head was about 24 hr, exclusive of time required for repairs. Radiation and contamination problems should increase the time compared with that needed to repair a conventional power plant boiler.

In July, 1958, the circuit breaker controlling one of the 4,000-gpm primary-coolant pumps opened. Inspection of the electrical wiring and pump interior showed no defects. The radiation level of the impeller and shroud, which had been in contact with the primary water, was about 2 r/hr on contact. A total of 74 hr was spent to disassemble, inspect, assemble and test the pump (*13*).

Since the SM-1 also serves as a training facility, student military personnel have reduced loss of time or overexposure of personnel while performing special maintenance work. Package power reactors are designed to operate at a remote site with a minimum number of personnel. In this case, the activity levels will probably increase the complexity of and time required for special maintenance tasks.

Effect on operations. Activity in the primary system has affected reactor

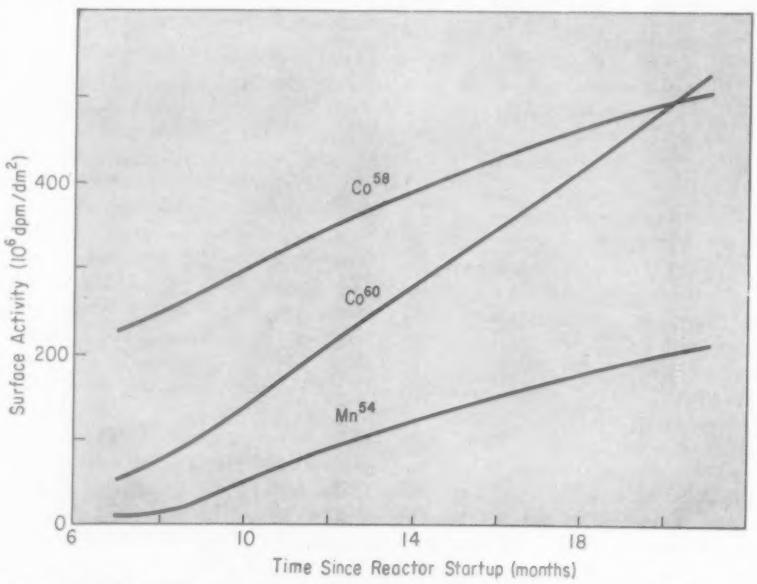

FIG. 3. CALCULATED increase of radiation levels on SM-1 steam generator baffle plate compares well with measured values

operations in several areas.

The time required for primary-water sampling is longer than in the case of conventional power plants because of necessary health-physics precautions.

Many of the sampling locations are in the demineralizer room, where radiation levels have increased. This rapid buildup is due to two factors: (a) the demineralizers, which function both as a primary-coolant filter and demineralizer, have accumulated a considerable amount of crud; (b) crud has collected in certain tees and stagnant portions ("dead legs") of the purification piping. After a year of operation, radiation levels near some of the dead legs were about 2 r/hr.

A sintered stainless-steel filter, which is located downstream of the demineralizers to remove resin fines and small crud particles, at times reaches 6 r/hr. To be cleaned, the filter is placed behind lead bricks and boiled in hot water and acid for several hours. The radiation level is generally reduced to 200 mr/hr. Some radioactive particles have passed through this filter and settled on the bottom of the primary make-up tank, increasing radiation levels at this point to 200 mr/hr.

Except in the areas mentioned (and in the vapor container), other parts of the power plant are free of radiation. No detectable dose rate has been found in the control room, turbine room or electrical room.

Buildup Reduction

Experience gained in the operation of pressurized-water reactors has revealed certain areas in which improved design should reduce activity buildup. Further experience should reveal additional areas.

Core-materials selection. Materials that yield long-lived gamma emitters upon irradiation should be minimized or avoided. For example, Haynes-25 alloy is used as a flux suppressor in several of the SM-1 fuel elements; the alloy is 50% cobalt, which is undesirable. Although the surface area of the material exposed to the coolant is relatively small, a major part of the Co^{60} in the SM-1 is thought to originate from this alloy.

Specification of impurities. Activation of impurities in stainless steel must also be evaluated. However, to evaluate the effects of the impurity levels of in-flux materials, it is necessary to determine the activity level of unavoidable nuclides (arising from basic constituents of stainless steel) such as Co^{58}, Fe^{59}, Mn^{54} and Cr^{51}. The specification of extremely low impurity limits may not be justified. Stainless-steel impurities can be reduced to such a low level that their contribution would be insignificant in comparison with the contribution from the unavoidable nuclides (*14*).

Selection of impurity levels depends on the cost of materials and the resulting reduction in activity levels. There is a practical lower limit for impurities below which only a slight reduction in dose rate is possible at much greater material cost. Pancer and Zegger (*14*) found a practical lower limit of 0.02% cobalt.

A number of steel companies have offered to supply special heats of low-impurity-content stainless steel. Estimated premiums vary from $0.05 to $4.00 per pound over base price. The exact price paid for low-impurity stainless depends on several factors, including the maximum impurity level allowable and the amount of steel ordered. For a maximum limit of 0.02% cobalt for type 304 stainless plate, one steel mill has indicated a price of $2.41/lb. Prices for low-impurity steels should decrease considerably if sufficient demand develops.

Low-flow areas. Stagnant or low-flow areas in the reactor primary system, which act as "crud traps," should be avoided. Unavoidable traps should be provided with drain or bleeder connections to flush out crud accumulations. A possibility is putting the tap-off to the primary by-pass purification system in a high-crud-concentration area.

Out-of-core materials. Although the use of materials other than stainless in out-of-flux areas will probably affect activity buildup, the magnitude of the effect is not yet certain. In studies we conducted (*2*), Croloy 16-1 test coupons accumulated about 3 times more activity than type 304 s.s. coupons when exposed to SM-1 coolant. Inconel is being considered for steam generators and piping in pressurized-water reactors; because of the high nickel content of this alloy (and correspondingly high cobalt content), its effect on system activity is important. Lack of operating data makes it difficult to estimate the effects of large out-of-core Inconel surfaces on activity buildup (*15*).

Solomon and Vogel (*11*) have reported in-pile loop studies in which surfaces in the out-of-pile section of the loop consist of ¼ Inconel–¾ stainless steel. Results indicate that the radiation field of this loop would be 6% greater after three years of operation than a loop with all out-of-core surfaces of stainless. For a loop of ⅔ Inconel–⅓ stainless, extrapolation would give a 22% higher activity after three years of operation than an all-stainless loop.

Coolant chemistry. High coolant *p*H, it has seen suggested, would reduce corrosion rates and reduce the release rate of crud from the core. The effects of coolant chemistry on activity buildup, however, are not completely known. For example, activity data have not been obtained on a pressurized-water reactor with stainless-steel-clad fuel elements and coolant at high *p*H (9.5–10.5). The SM-1 is operated at a nominally neutral pH (7–8).

* * *

Experimental data was obtained for the Army Nuclear Power Program under U. S. Atomic Energy Commission contract AT(30-3)-326.

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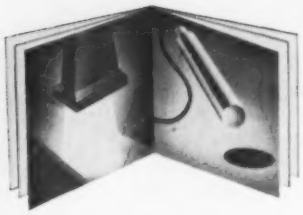

Radioactive Gages

APPLIED RADIATION CASE HISTORY NO. 5

Gas-turbine engines for airplane propulsion make ever-increasing demands for greater inlet temperatures to promote greater efficiencies. The eventual limit is the melting temperature of metal parts. After metallurgists have done all they can to improve their alloys, a further improvement is to cool blades and vanes by running air through them. One way is to cast hollow vanes and blades; another is to drill cooling passages through solid ones.

This air cooling creates a new problem: After you have made an air-cooled member, how do you measure the thickness of its surfaces, already designed as thin as possible to make them light? The two stories that follow are two answers to this question. One group of engineers fills hollow castings with a radioactive liquid and finds thicknesses by measuring gamma transmission. Another puts a radioactive probe into cooling passages and measures beta transmission as probe and detector scan together.

I. Liquid-Source Gage for Hollow Blades and Vanes

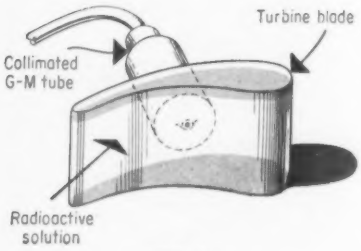

FIG. 1

To find out whether a complicated casting is thin enough to be light, thick enough to be strong, fill it with a gamma-emitting solution and measure transmission at appropriate surface points

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Research Laboratories, General Motors Corp., Warren, Michigan
and WILLIAM L. SHELLY
Allison Division, General Motors Corp., Indianapolis, Indiana

HOLLOW TURBINE BLADES and vanes, recently added to the design of a turbine-propeller airplane engine, pose the problem of how to measure surface thicknesses without destroying the specimen. If the cores shift during casting, the blade or vane may be too weak to use.

Our answer to the problem is to fill the specimen (blade or vane) with a liquid solution of a gamma-emitting nuclide and count the photons that escape with a narrowly collimated miniature G-M counter (Fig. 1). Using a jig that accurately positions the detector, we measure transmission at 12 selected points on each specimen. Measurements with metal wedges tell us the shape of a standard curve that gives counting rate as a function of thickness. Sectioning a few specimens in any batch gives us calibration factors that relate the standard curve to the source specific activity and the geometry at each of the sampling points. The thicknesses we measure with our liquid-source gamma-gaging technique are generally within 3–10% of optical measurements of sectioned specimens.

Turbine Design

A gas-turbine engine consists of a compressor, which increases the pressure of incoming air; a combustion chamber, which heats and expands the air at constant pressure; and a turbine to extract energy. In a pure jet only a little of the energy drives the turbine; most of it provides forward thrust from the recoil of exhaust gases. In a turboprop like the Allison T-56, 80–90% of the power drives a geared propeller, and only the remainder provides recoil.

We are concerned with the turbine assembly, a wheel with a number of turbine blades (sometimes called "buckets") and a stator with turbine vanes that deflect hot combustion gases to the wheel. Although most blades and vanes are solid, a new design, intended to increase the power of the T-56, has hollow ones in the first stage. Coolant gases flowing through vanes and blades enable introduction of hotter combustion gases than otherwise.

The new vanes and blades, as shown in Fig. 2, are made with posts between their walls by casting a high-temperature nickel-base alloy, GMR-235, into

for Air-Cooled Turbine Blades

a mold with a ceramic core. If the core shifts when pieces are cast, variations in wall thicknesses result. We had to have wall-thickness measurements to complete the development of the engine.

Because of the external geometry and internal construction of blades and vanes we could not make mechanical measurements or usual types of nondestructive tests.

When the problem came to the General Motors Research Isotope Laboratory, we decided after some preliminary experimentation that a liquid-source method would probably work. A specific advantage is that it offers the versatility required in the event of design changes in blades or vanes.

Nuclide and Detector

As a radiation source we wanted a gamma emitter with a photon energy that would produce a maximal change of signal for a minimal change of wall thickness. Theoretical calculations of narrow-beam absorption gave us a preliminary guide. Using this we considered several possibilities from the General Electric Chart of the Nuclides. After we had chosen Sm^{153}, experimental measurements with step wedges of GMR-235 confirmed our judgment.

Photon energy. Since our measure of thickness is really our change in counting rate, one criterion for the best gamma energy is that it provide a maximal change in fractional absorption when the thickness changes from the minimum in which we are interested to the maximum. Using symbols we state that the following expression shall have a maximum: $\Delta(I/I_0) = e^{-0.010\mu} - e^{-0.050\mu}$. ($I$ = transmitted intensity; I_0 = incident intensity; μ = absorption coefficient in reciprocal inches; 0.010 and 0.050 are maximal and minimal thicknesses in inches.)

Because it gave us a useful, readily computed approximation, we plotted $\Delta(I/I_0)$ as a function of energy (Fig. 3), assuming narrow-beam geometry and monoenergetic photons. Since μ as a function of energy is not known for GMR-235, we used values for copper (densities and effective atomic numbers are about the same). The figure indicates that 55 kev is the best energy.

Nuclide. A search among the nuclides shows that several can be used; among them are the following:

Nuclide	*Major photon energy (kev)*	*Half-life (days)*
Tm^{170}	84	129
Sm^{145}	61	365
Sm^{153}	103, 69	1.95
Pd^{109}	88	0.57
Cd^{109}	87	475

Considerations of cost, availability, half-life and chemistry led us to Sm^{153} as best suited to our purpose.

Although the gamma energies of Sm^{153} appear to be rather large, measurements confirmed our feeling that the effective energy for absorption purposes is much lower than primary photon energies. The 103-kev and 69-kev photons of Sm^{153} are emitted in the ratio of 4.25 to 1, respectively; averaging gives an effective energy of ~101 kev. But counting geometry, scattering processes and variation of detector efficiency with energy imply a much smaller effective energy. We plotted absorption of Sm^{153} gammas as a function of thickness of GMR-235 and found an absorption coefficient corresponding to 60 kev, close to the ideal.

We get our samarium in a standard irradiated unit available every Monday from Oak Ridge National Laboratory. The target, which costs $15 plus $23 irradiation charge, is contained in an aluminum tube and consists of 0.03 gm of Sm_2O_3. After irradiation it contains ~50 mc of Sm^{153} activity.

After we receive it, we add some 1 *M* hydrochloric acid to the aluminum tube to dissolve the Sm_2O_3 and then add more 1 *M* hydrochloric acid in a volumetric flask to bring it to volume.

One thousandth of a per cent of

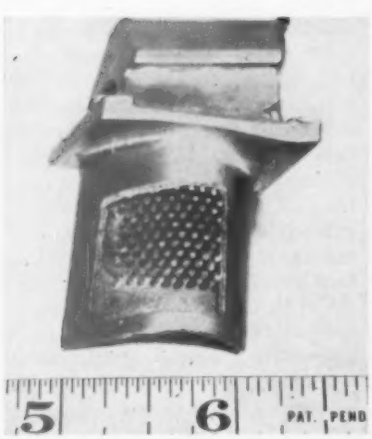

FIG. 2. HOLLOW TURBINE BLADES AND VANES have posts between two surfaces. If casting core shifts, surfaces may be too thick for cooling or too thin for support

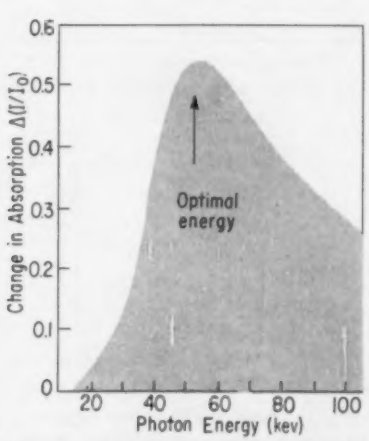

FIG. 3. MONOENERGETIC ABSORPTION curve shows 55 kev is best photon energy

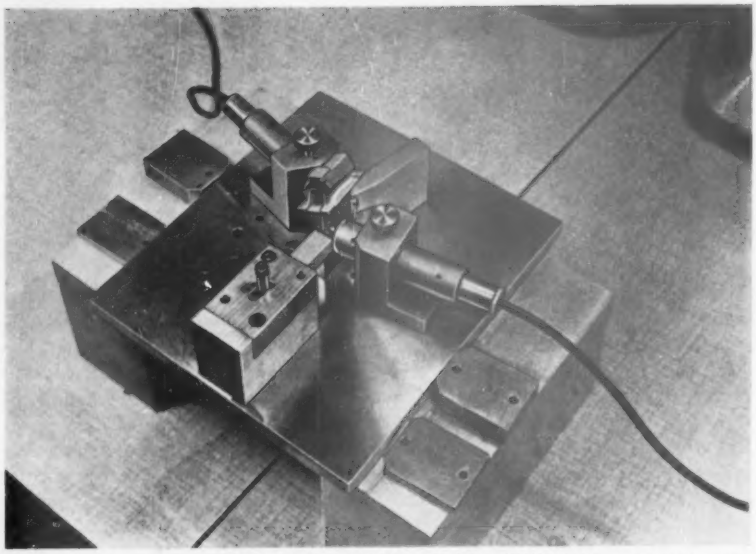

FIG. 4. JIG HOLDS G-M COUNTER AGAINST BLADES AND VANES at selected points. Transmission of gammas from liquid source inside specimen indicates whether thickness matches calibration obtained from sectioned samples

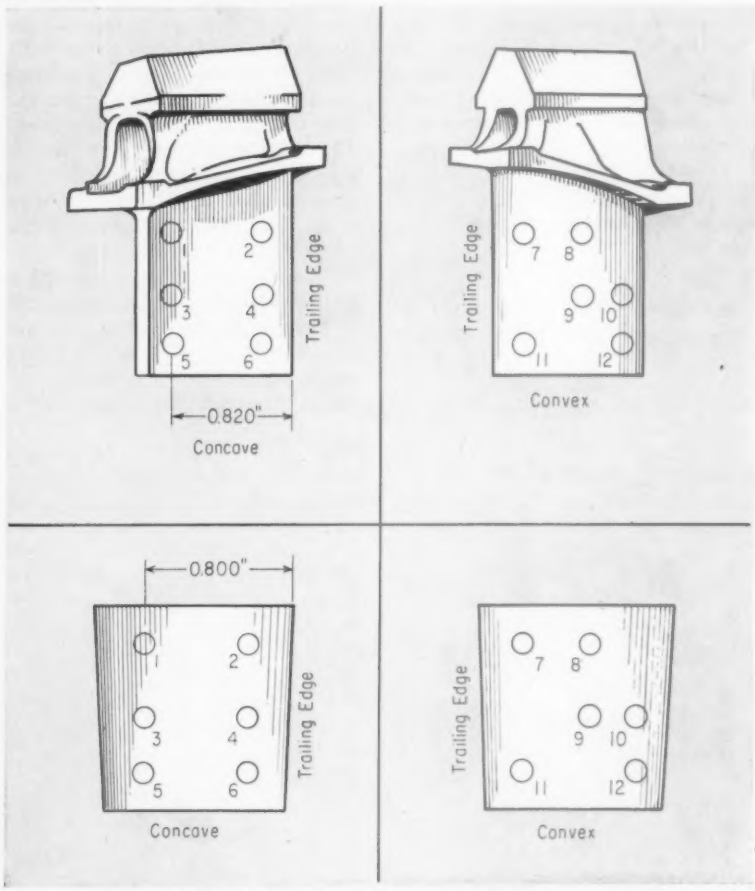

FIG. 5. TWELVE COUNTING POINTS, SIX ON EACH SURFACE of each blade and each vane are chosen to show operator whether core has shifted during casting. If it has, transmission will be too great at some points, too small at others. Pattern usually has enough detail to show nature of any core shift. 12-point examination takes 7–8 min

polyoxyethylene sorbitan monolaurate (Tween 20) serves as an effective wetting agent and prevents air-bubble formation. After a blade or vane has been sealed at one end with double-faced adhesive tape, the 10-mc/ml samarium solution is injected through the open end with a 3-in. 22-gage hypodermic needle.

Detector. After we had considered two other types, we chose for our detector a small lead-collimated G-M tube (Anton 222, 0.35 in. diameter, 2.7 in. long, 700 volts). The tube is a rugged beta-gamma detector with a 1.4-mg/cm² window; preliminary tests showed us that it has a small background and a fairly wide plateau. Although its efficiency for Sm^{153} gammas is probably much smaller than that of other detectors, by adjusting the concentration of our source we get a good enough signal-to-noise ratio to ensure good statistics in 1-min counts. A ⅛-in. collimating hole gives us good enough spatial resolution.

Because it has large efficiency for gamma radiation, we considered a thallium-activated sodium iodide crystal. Size was a problem; the smallest commercial photomultipliers at the time were ¾ in. in diameter and would require a specially made crystal. Moreover if we adapt our method to production, temperatures will be bad for photomultiplier operation.

The jig shown in Fig. 4 holds our detector against six selected points on each surface of a blade or vane (Fig. 5).

Measurement

An unusual aspect of this gaging problem is that source activity at different measurement points is not constant because of nonuniform interior shape. Thus we cannot use a common transmission curve to determine thickness from counting rate; indeed such a procedure would require 24 such curves. Since the radiation is of constant quality but varying quantity, all of these curves would be parallel. We find it easier and more expedient, therefore, to use what we term a "primary" transmission curve (Fig. 6) determined by absorption measurements with Sm^{153} and GMR 235 wedges. We then compute a calibration factor for each measurement position so that it is only necessary to multiply each counting rate by the appropriate factor to use the single curve for all thickness determinations.

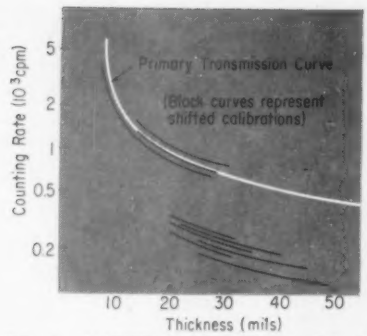

FIG. 6. MASTER CALIBRATION is shifted in sections, one for each point

We compute calibration factors from measurements on standards, a number of processed vanes, chosen at random, sectioned and measured optically. With later shipments of samarium we merely adjust the curve according to specific activities of prepared solutions.

In two glove boxes side by side we fill blades and vanes and count them. Counting times vary with specific activity, but the usual interval is 1 min for each point. After examination we decontaminate blades and vanes by soaking them for a short time in dilute hydrochloric acid. With two detectors a 12-position examination can be completed in 7–8 min.

Results

When we wanted to test the accuracy of our method, we used both gamma gaging and optical measurement of sectioned samples to find thicknesses in three blades and three vanes. Of the 72 points at which we made comparisons, only five showed discrepancies greater than 10% (points 4 and 6 on one blade; points 3, 4 and 6 on another). All these points are at trailing edges, and since thickness changes rapidly there as a function of position, slight errors in location of the optical measurements may cause the discrepancies.

It is interesting to observe core shifts in some specimens. For example, in one blade, measurements at positions 2, 4 and 6 indicate that the surface is thicker toward the base on the concave side, and measurements at positions 7 and 11 show that it is thinner toward the base on the convex side.

II. Scanning Beta Gage for Cooling-Channel Walls

Using a modified medical scanner, engineers trace wall thicknesses by inserting a beta-emitting probe into cooling channels and recording counting rates from a stilbene scintillator

By HERBERT E. FARMER
General Electric Co., Lynn, Massachusetts

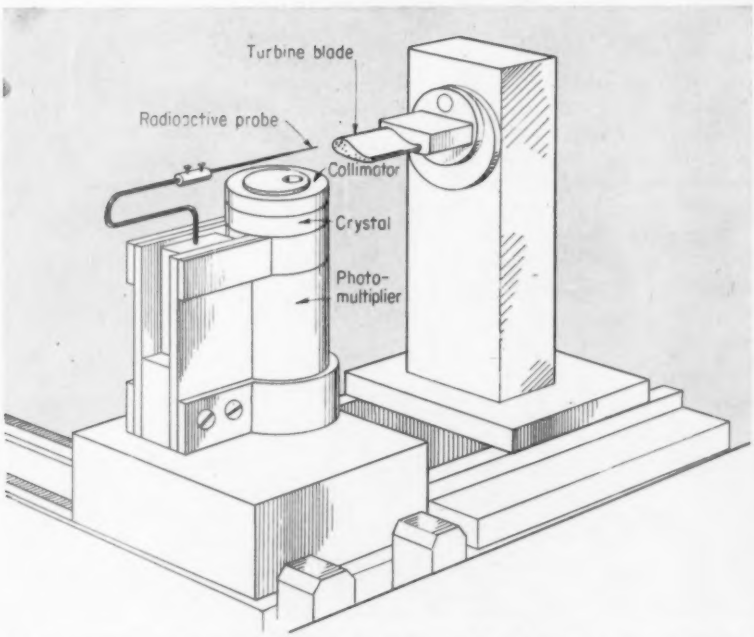

FIG. 1. MOVING BETA-EMITTING PROBE AND DETECTOR scan length of cooling channels placed in blades to pass cooling air. Stilbene scintillator counts particles from Sr^{90}-Y^{90} source to test thickness of channel walls

FOR AIR-COOLED turbine blades developed by our Flight Propulsion and Jet Engine departments, we need an instrument to make quick, accurate, nondestructive tests of cooling-passage wall thicknesses. The system we have developed is a scanning beta gage. After a blade is clamped in a test position, a radioactive probe and a detector move forward together (Fig. 1). The probe goes into the channel under test, while the detector passes under the blade. As the system scans the length of the blade, the counting rate determines whether wall thickness is within specified limits.

Gage Design

The passages we measure, visible in Fig. 2, are 3–7 in. in length and 50 or 60 mils in diameter. In one of our buckets the nominal thickness is 30 mils, and tolerances are +0 and −20 mils. We could find no commercial gage adaptable to the problem.

Probe. Our source of beta particles is 0.3–0.4 mc of Sr^{90}-Y^{90} in the end of a

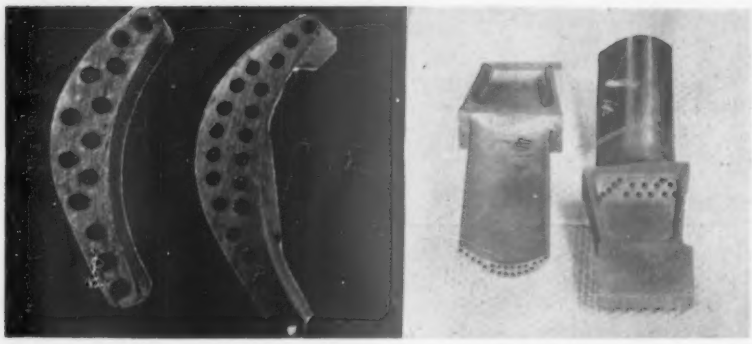

FIG. 2. COOLING PASSAGES IN BLADES are 3–7 in. in length, 50 or 60 mils in diameter. One example of a nominal thickness is 30 mils. Scanner traces counting-rate curve along channel; operator compares with standard curve

hollow stainless-steel needle. It is ⅛ in. in length and is surrounded by a 6-mil wall. For 60-mil passages we use a 50-mil-o.d. needle; for 50-mil passages, a 40-mil needle.

The probe is prepared as are interstitial needles for radiotherapy. After a ⅛-in.-long, 0.040-in. diameter ceramic slug has absorbed 10 μl of 30-curie/liter Sr^{90} solution, it is placed ⅛ in. from the needle tip. Our probe-detector distance, which is critical, is a half inch, the minimum value for which an edge of the bucket will not touch the detector.

A Lucite housing surrounds the probe, which is held in an adjustable, flexible mount. So that the probe enters the proper passage as it advances, a template-and-pantograph lever system aligns the blade. Rotation about an axis puts the blade in one of two positions separated by 180 deg; levers move it vertically and horizontally.

Detector, scanner. Our detector is a 1-in.-diameter by 1/16-in.-thick stilbene scintillator shielded by a 30-mil collimator with a ⅛-in. hole and coupled to an RCA 6655 photomultiplier. From this the signal goes by way of a precision ratemeter to either a recorder or a go–no-go control. A modified Tracerlab Tracer-Scanner moves the whole assembly at ~3 in/min.

Accuracy

Although the complexity of our geometry makes good calculations impossible, we made simple assumptions to compute the source strength required for ±0.2-mil accuracy in our thickness measurements. With exponential absorption the minimum thickness difference one can detect, Δx, is related as follows to counting rate n, confidence level K, absorption coefficient μ and electrical time constant τ: $\Delta x = K/\mu(2\tau n)^{1/2}$ (*1*).

After we had built the system, we calibrated it by comparing counting rates with thicknesses measured by another method. To calibrate and also to check our accuracy we scanned 13 channels in each of three blades, sectioned the blades at five places, measured thicknesses at each end of each section with a traveling microscope and compared values.

As you see in Fig. 3, our experimental calibration curve has two breaks. Beyond the greatest measurable thickness the curve becomes flat, indicating that this break corresponds to the greatest useful range of the Y^{90} 2.26-Mev beta particles. [Computation shows that monoenergetic 2.26-Mev electrons have a range of 150 mils in aluminum (*2*). Since our metal is 2.9 times as dense as aluminum, we anticipate a maximum useful range of 50 mils.] Self-absorption in the source and the continuum of energies in the beta spectrum probably shorten our maximum useful penetration to the 42 mils of the second break of Fig. 3.

The first break is probably explained by saturation backscattering.

By statistical analysis of 117 paired beta and optical thickness measurements on our three sample blades, our accuracy at the 95% confidence limit is ~±2 mils in the thickness range 20–27 mils and ~±3 mils in the range 27–41 mils. The theoretical expression shows that counting statistics account for ±0.3 mil and ±1.3 mils in these ranges. The rest of our error is doubtless caused by instabilities and our multiple-hole configuration.

Since our present accuracy is good enough to do the job, we have not made a careful investigation of contributing errors although several improvements are available if we need greater accuracy. For example, we have made only one calibration curve; the complexity of our geometry makes plain that a calibration for each passage would be appropriate. That our precision, measured by repeatability, is good is shown by Fig. 4, which we regard as our worst case.

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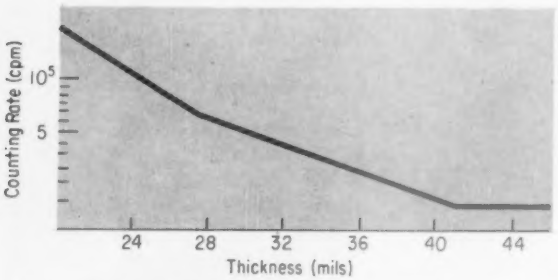

FIG. 3. CALIBRATION PLOT of thickness against counting rate has breaks at maximum beta range and backscattering limit

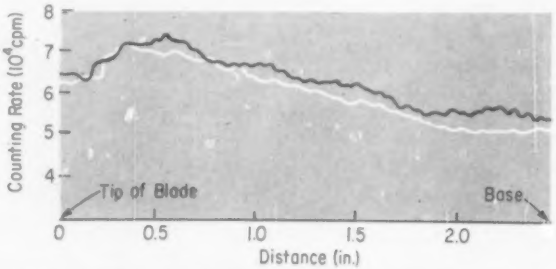

FIG. 4. GOOD REPEATABILITY is shown by tracings of "worst case." Accuracy is everywhere better than 10%

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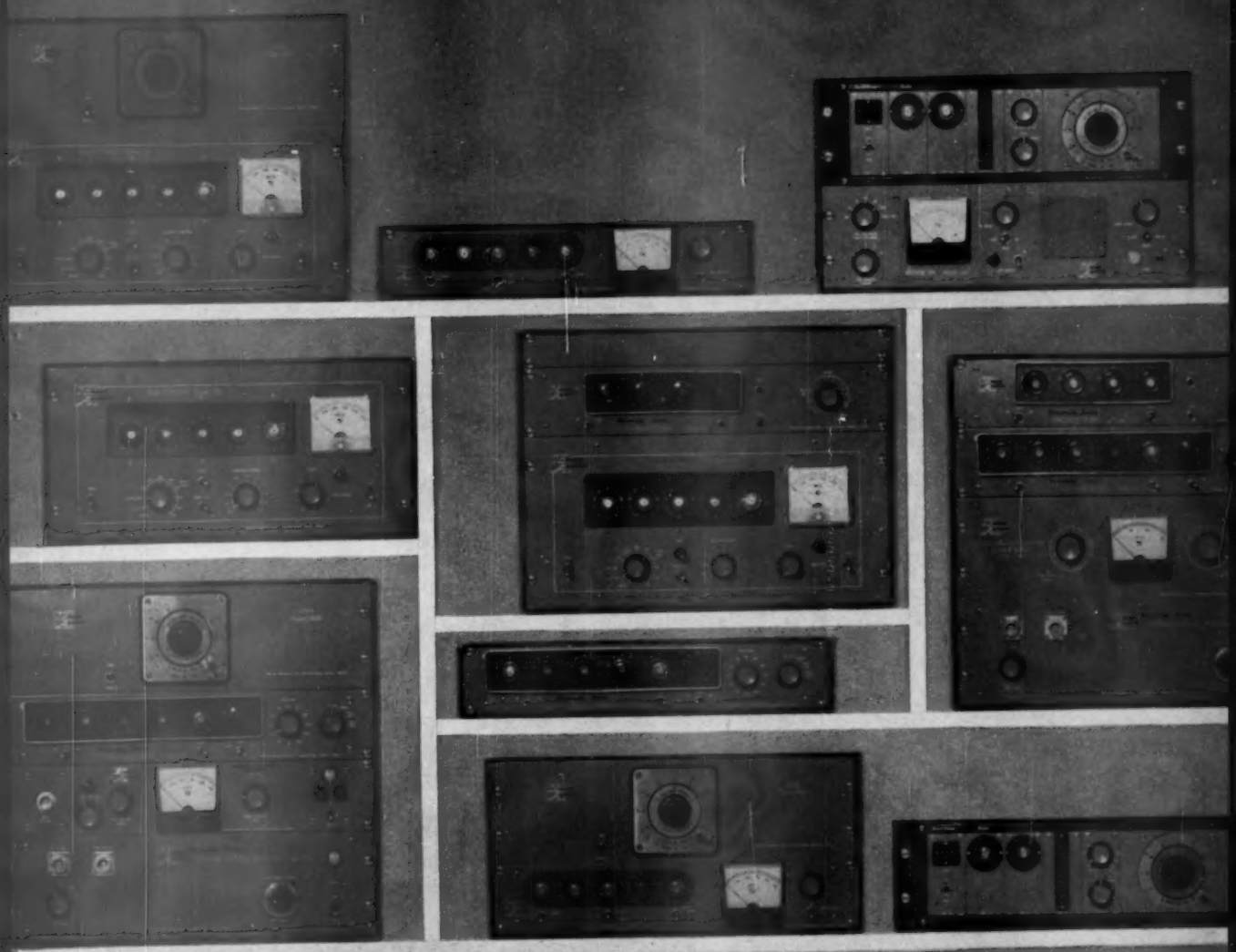

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Transistor Amplifier for Fast Proportional Counting

By JOHN B. S. WAUGH* and ROY W. NICHOLSON
Atomic Energy of Canada Ltd., Chalk River, Ontario

A transistor amplifier, developed at Chalk River for exacting standardization work with 4π beta flow counters, has counting-rate plateaus over 200 volts long with slopes less than 0.2% per 100 volts (Fig. 1). Comparable performance at repetition rates up to 50,000 cps has not been previously reported. Current-pulse amplification, permitted by the wide-band transistor circuits, makes the fast counting rates feasible.

The faster counting rates possible with proportional counters (their deadtime is smaller than that of G-M counters) makes them useful for measuring total source activity. Such counters are generally used in the region of high gas multiplication for detecting low-energy particles.

The main problem in such a system is that high-energy particles produce large output pulses, which heavily overload the electronic system. Plateaus with steep positive or negative slopes at high counting rates often result; the former are usually caused by insufficient sensitivity in the amplifier-discriminator system; on the other hand, a region of negative slopes is thought to be mainly due to an extension of the system deadtime after heavy overloading.

For a standardization system such as the one described here, plateau slopes of 0.1% per 100 volts are desirable at rates up to 50,000 cps. In addition to adequate bandwidth and gain, deadtime should be about 1 μsec to keep counting-loss corrections small.

Signal-Pulse Formation

The pulse-formation mechanism in gas-filled counters is fairly well understood (*1–4*). In the normal proportional counter, a primary ionizing event initiates an avalanche of charge in the high electric field close to an internal fine-wire electrode. In the usual system, the charge induced on this electrode produces an output voltage pulse equal to Q/C, where Q is the induced charge and C is the capacitance of the output electrode system (including input capacitance of the associated amplifier circuit). Preoccupation with voltage pulses stems from the high input impedances of earlier electronic amplifying devices.

Transistors, on the other hand, have comparatively low input impedances, which suggests feeding the current pulse ($= dQ/dt$) produced by the counter into a low-input-impedance current amplifier. The current-pulse amplitude, as shown by Fig. 2, returns to zero by the time the voltage pulse reaches its maximum value.

Direct amplification of the short-duration current pulse aids in obtaining smaller deadtime, thereby allowing operation at greater counting rates. We therefore investigated low-input-impedance current amplifiers with effective overload protection for this application.

Circuit Details

As shown in Figs. 3 and 4, the input stage is a peak-current limiter consisting of diodes *CR1,2* and resistors *R1,2*. In the present arrangement, suggested by Goulding (*5*), a current of 50 μa is defined in *CR2*, and a smaller current, ~10 μa, flows in *CR1*. Negative input signals tend to turn *CR1* on and *CR2* off. The diode dynamic impedances change so that *CR1* shunts large input signals directly to ground, while the impedance of *CR2*

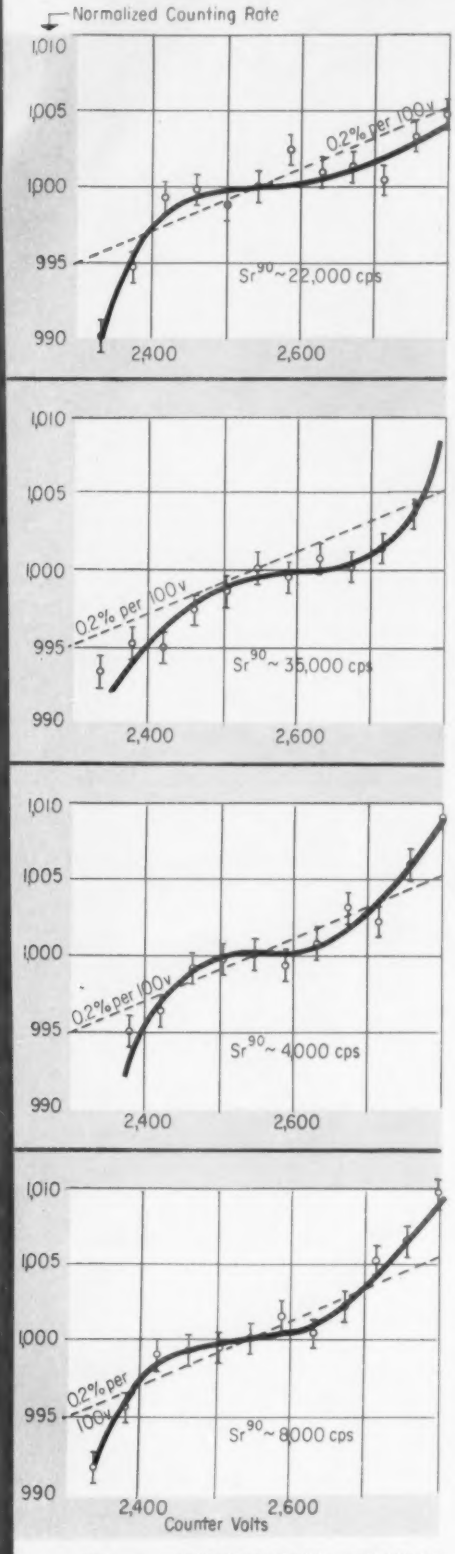


FIG. 1. PROPORTIONAL-COUNTER PLATEAUS for 4,000, 8,000, 22,000 and 35,000 cps from Sr^{90} sources. Plateaus are >200 volts long; slopes are <0.2% per 100 volts

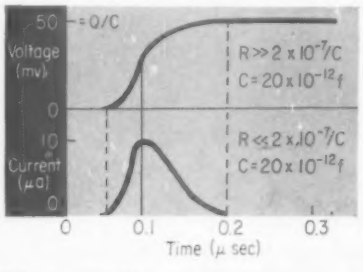
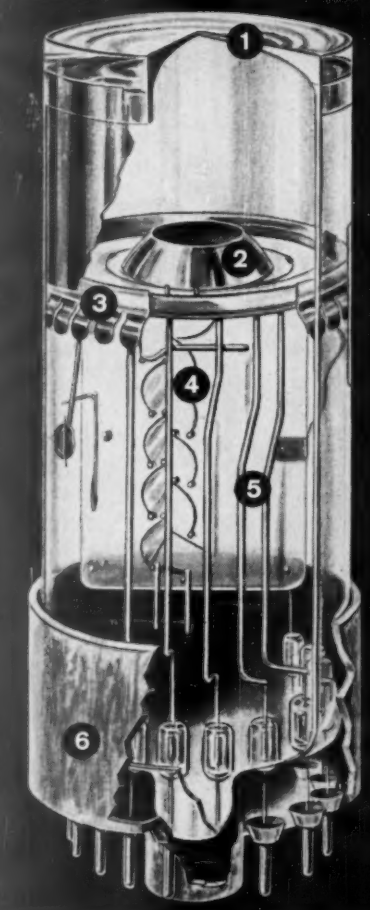


FIG. 2. SHAPES of proportional-counter voltage (top) and current pulses (bottom)

* PRESENT ADDRESS: Research School of Physical Sciences, Australian National University, Canberra, A.C.T., Australia.



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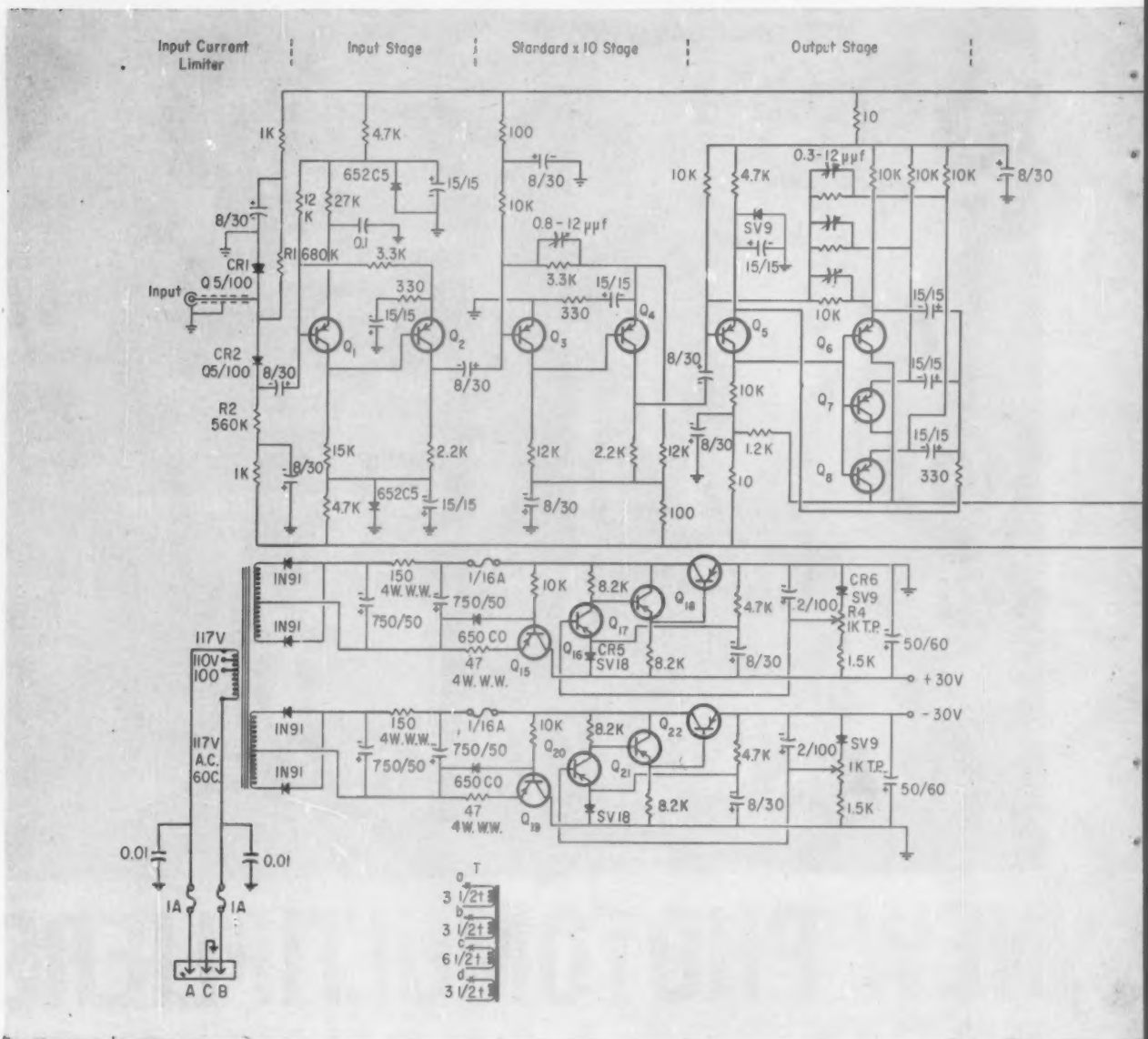


FIG. 3. CIRCUIT OF TRANSISTOR AMPLIFIER. Low-input-impedance transistor stages permit current-pulse amplification with short deadtime and high counting rates. Power supply, at bottom of diagram, supplies ±30 volts

rises and isolates the amplifier input. The limiting action of *CR2* is intrinsically fast because the current switching occurs in very-low-impedance circuits. However, diodes with small minority carrier storage, shunt capacitance and series resistance are required for most effective operation.

Transistors *Q1,2* form a current feedback pair with a gain of 10. Surface-barrier transistors (type 2N128) in this stage provide the lowest possible noise (*6*), which at present limits the maximum usable gain.*

Transistors *Q3,4* form an almost identical stage except for the greater bias required for the 2N384 drift transistors. The phase-advance capacitor *C9* is adjusted for just visible overshoot in the output-current wave-

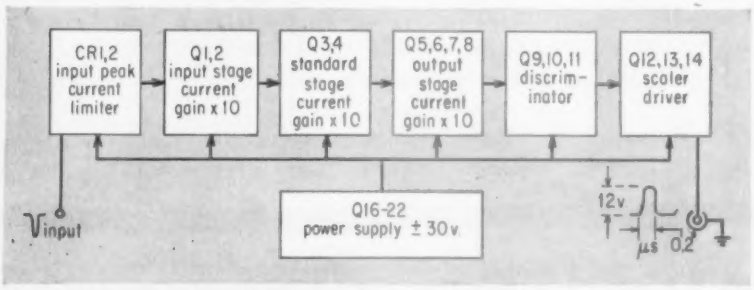
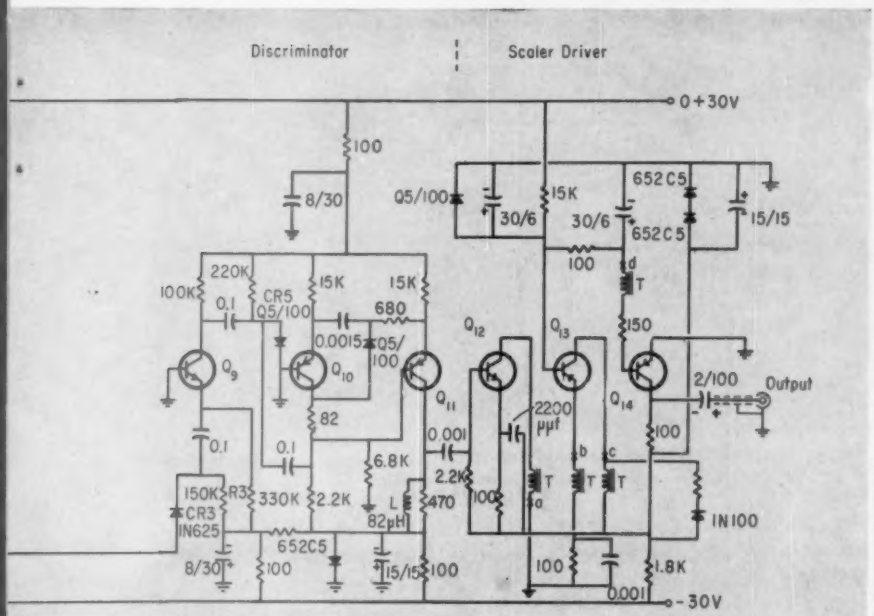

CR1,2 input peak current limiter
Q1,2 input stage current gain x 10
Q3,4 standard stage current gain x 10
Q5,6,7,8 output stage current gain x 10
Q9,10,11 discriminator
Q12,13,14 scaler driver
Vinput
Q16-22 power supply ± 30 v
12v
μs 0.2

FIG. 4. TRANSISTOR-AMPLIFIER block diagram. Three feedback stages give over-all gain of 1,000. Maximum output of third stage is 12 volts with rise time of 0.15 μsec. All stages operate from series-stabilized ±30 volts

* Note (added in proof): More recent work has shown the 2N393 (a micro-alloy type) to be somewhat superior in this respect (see reference 7).



Note:
Capacitors in mf, resistors 1/2 w 5 % comp.

Transistors	Types
Q_1, Q_2	2N128
$Q_3, Q_4, Q_5, Q_6, Q_7, Q_8$	2N384
Q_9	2N167
Q_{10} Q_{11}	2N393
Q_{12}	2N440
Q_{13}, Q_{14}	2N604
$Q_{15}, Q_{18}, Q_{19}, Q_{22}$	2N1043
$Q_{16}, Q_{17}, Q_{20}, Q_{21}$	2N43A

form for a step input of 100 μa. It is necessary to decrease the collector-circuit time constant by shunting the load with a much smaller resistor (e.g., 220 ohms) to observe the true current waveform. The following (low-input-impedance) stage must be removed, of course.

Transistors *Q5,6,7,8* (the latter three in parallel) form the output feedback stage. This stage was originally designed for a double-delay-line amplifier and will produce a maximum output of ±12 volts. To allow for both polarities, the emitter of *Q5* is biased 9 volts positive with respect to ground. The collector of *Q5* and combined bases of *Q6,7,8* are near ground potential, while the output collectors are at about −16 volts. This permits the large output-voltage swings without approaching either the low-current or collector-base-voltage limits for the drift transistors.

Diode *CR3* and resistor *R3* determine the maximum current that can be injected into the emitter circuit of *Q9*, the collector circuit of which provides a high-impedance source to drive the current-operated discriminator (*8*) consisting of diode *CR4* and transistors *Q10,11*. The discriminator threshold is set at about 70 μa, and its deadtime is about 1.5 μsec.

The output of the discriminator is peaked by *L*, and the positive edge is

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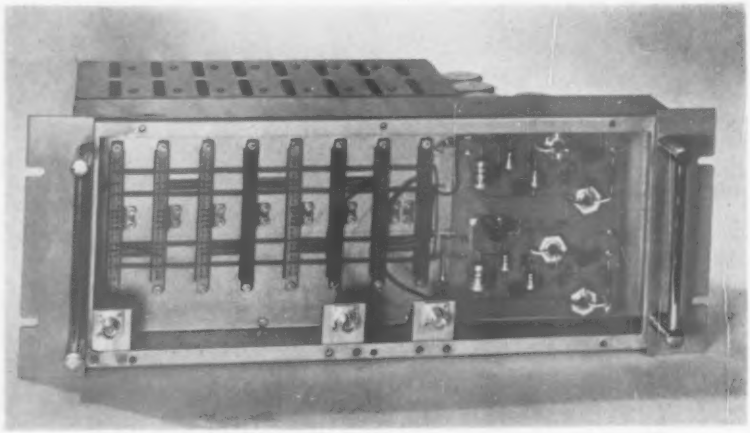

FIG. 5. AMPLIFIER UNIT with front panel removed; printed-circuit cards are inserted from rear. Wired-in double stabilizer board is visible on right

amplified by *Q12*, which drives the trigger winding on the blocking-oscillator transformer *T*. Transistor *Q13* is the blocking oscillator (*9*), and *Q14* is a power amplifier driven by the fourth winding on *T*. A 12-volt pulse of about 0.25 μsec width at the base is produced in the 100-ohm output impedance. The resolving time of this stage alone is 0.8 μsec, which is less than the discriminator deadtime. This condition is necessary if the discriminator deadtime is to be the only one determining counting losses.

The power supply consists of two identical circuits with opposite polarities grounded, giving ±30-volt lines. In the positive supply, *Q18* is the series stabilizer, while *Q16,17* form the feedback amplifier. Trimpot *R4* adjusts the output voltage and takes up tolerance variations in the reference elements *CR5,6*. Since transistor *Q15* has a defined emitter current, it limits the maximum short-circuit output current to this value. The current is defined at about twice the normal operating value to ensure that *Q15* remains well bottomed under this condition. The supply delivers 30 volts ±1% for 10% line variations and zero to full load (40 ma) from room temperature to 45° C. Peak ripple and noise are less than 1 mv under all conditions.

An amplifier unit and plug-in circuit boards are shown in Figs. 5 and 6.

The estimated detection sensitivity of the amplifier–flow-counter system is about 20 ion pairs in the primary ionizing event.

* * *

The author acknowledges the assistance of A. Grothe, who constructed and tested these amplifiers. The work has profited from discussions with V. H. Allen, A. R. Jones and F. S. Goulding. Thanks are due P. Campion for his continued interest and advice and also R. J. Brown for carrying out extensive tests in the Radioactive Standardization Laboratory.

The work forms part of the research program of the Physics Division of Atomic Energy of Canada Ltd. This article is based on Chalk River report CREL-828 and on a paper presented at the Canadian IRE Convention in Toronto, October, 1959.

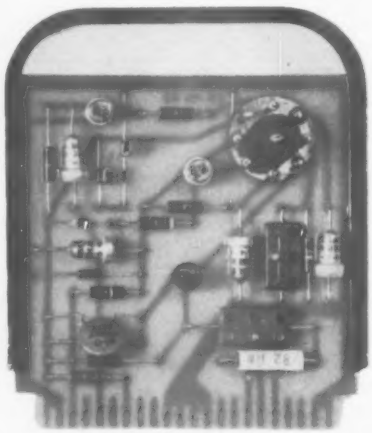

FIG. 6. TRANSISTOR PLUG-IN board is one of six for amplifier

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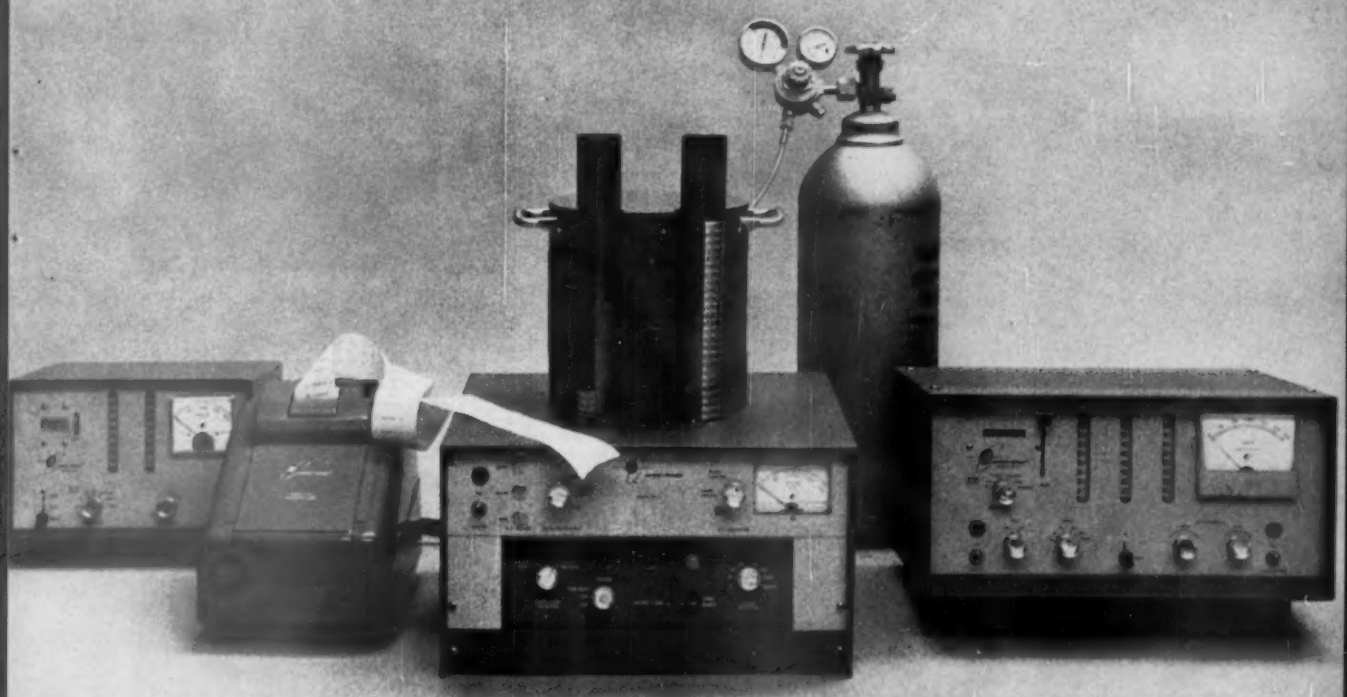

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Xenon-Krypton Separation by Gas Chromatography

By R. C. KOCH and G. L. GRANDY

Chemistry Department, Nuclear Science and Engineering Corp., Pittsburgh, Pennsylvania

A gas-chromatographic method developed in our laboratory is particularly suitable for separation of radioactive xenon and krypton prior to analysis of the radioisotopes. In conjunction with the separation method, techniques for sampling both static and dynamic gas systems have been developed. The method is applicable to reactor and fuel-processing plants for fission-gas measurements.

Gas chromatography has been widely used for separation and determination of components in complex gas mixtures (*1, 2*). The mixed gases are adsorbed on a fixed bed or on a liquid bed fixed on an inert base (*2*). The constituents are then eluted separately from the bed in distinct, successive volumes of sweep gas.

Gas chromatography is especially useful for gases whose similarity of chemical and physical properties would make their separation and assay by classical methods tedious or impractical. The method has been applied to both organic and inorganic gas mixtures, although its industrial application has been directed primarily to organic vapors.

The chemical inertness of xenon and krypton and the similarity of most of their physical properties render their separation by classical methods difficult. There are significant differences, however, in their adsorption, retention and elution from several adsorbents in dynamic gas systems (*3–6*). Therefore, we performed a series of tracer experiments to investigate the feasibility of separating xenon and krypton by gas chromatography and to determine a practical separation procedure. The tracers were 10.3-yr Kr^{85} and 5.27-day Xe^{133} with helium as the sweep gas.

Procedure

Two 0.4-in.-diameter chromatographic beds, 16 in. and 6 in. long and consisting of −40 +50 mesh activated charcoal, were evaluated in the apparatus shown in Fig. 1. The charcoal was packed firmly into U-tube containers. Small-mesh copper screens, which were soldered to the U-tubes,

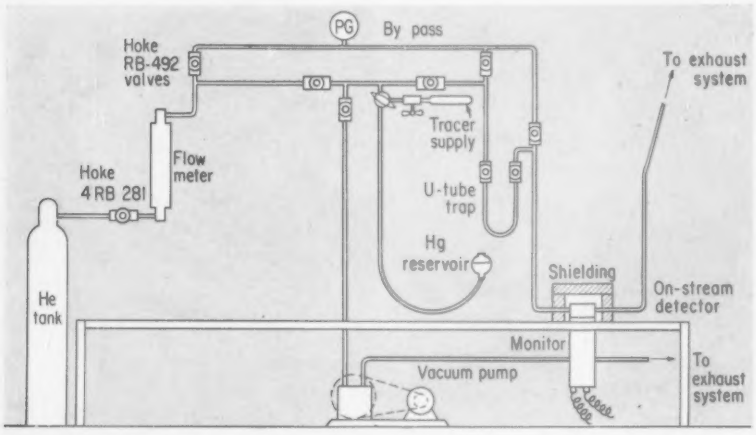


FIG. 1. EXPERIMENTAL APPARATUS for determining retention properties of charcoal beds for Xe and Kr consists of source of helium sweep gas, flow and pressure regulators and controllers, injection manifold for introducing Xe and Kr tracers, U-tube trap containing chromatographic column and radioactivity monitor (*7*) to measure tracer eluted from column. Monitor output is recorded continuously with counting-rate meter and strip-chart recorder. Tracers, diluted with helium, are contained in high-pressure capsules joined to manifold by gas burets

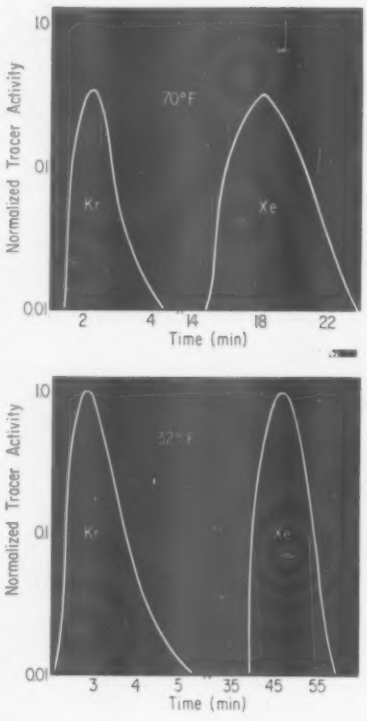


FIG. 2. STATIC-CHARGING METHOD and Xe-Kr separation on charcoal to 70° F and 32° F. In both cases, helium purge rate is 0.6 liter/min with 6-in. charcoal column

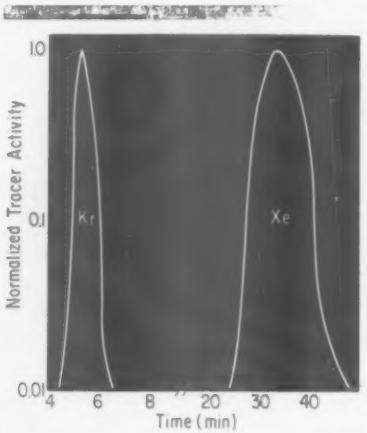
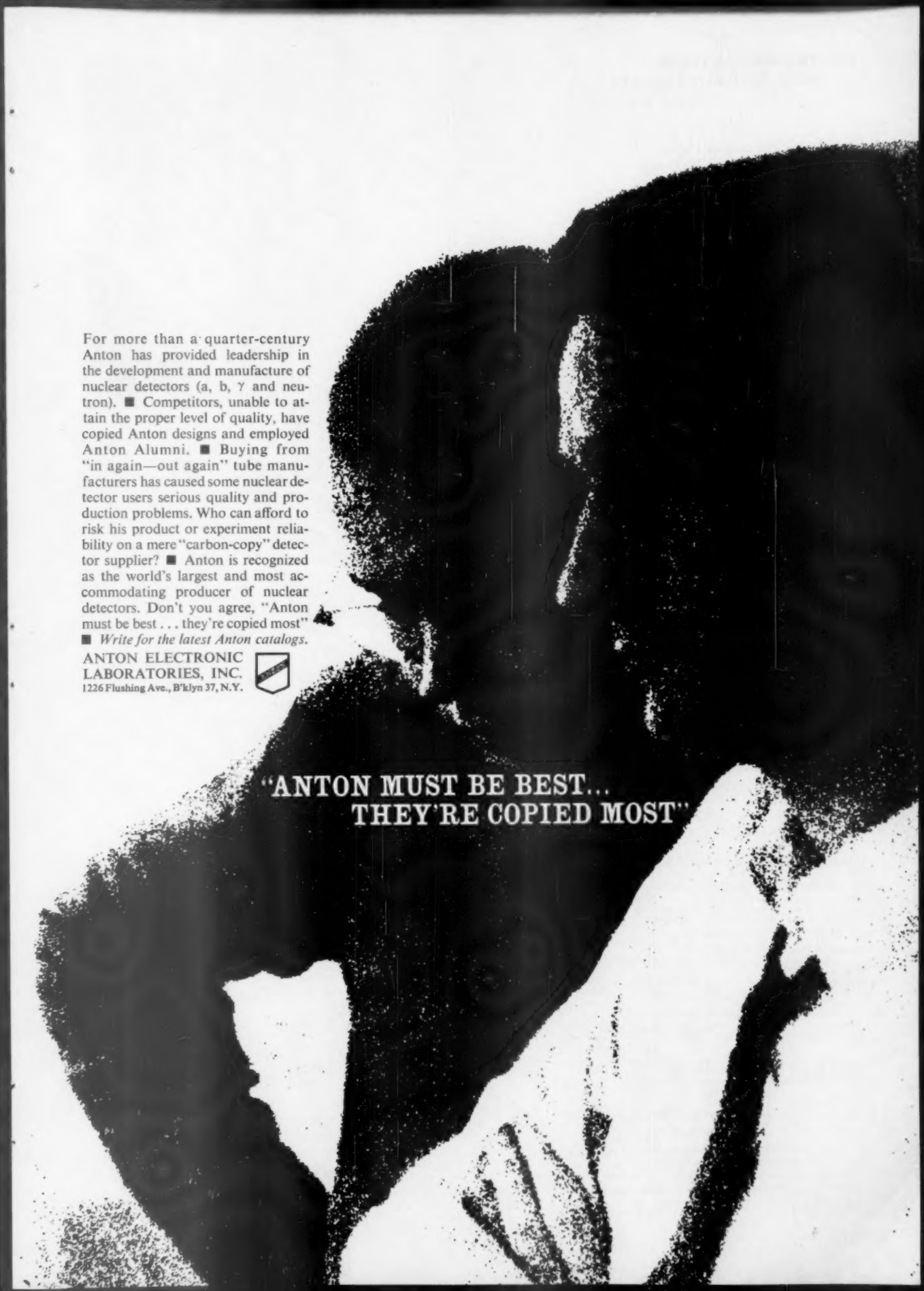


FIG. 3. DYNAMIC-CHARGING METHOD and Xe-Kr separation at 32° F. Helium purge rate is 0.6 liter/min and charcoal-column length is 6 in.



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This article starts on page 76

determined bed lengths and prevented dispersion of the charcoal through the system.

For a typical experiment, the chromatographic column was adjusted to the desired temperature, a suitable charge of tracer was introduced into the injection manifold, and the helium flow rate was established through the manifold by-passing the injection system. The helium flow was then diverted to sweep the tracer to the charcoal bed. Sweep gas flow continued until the radioactivity monitor indicated that the total tracer charge had been eluted from the charcoal. This method of charging the tracer simulates introduction of a static gas sample into a gas-chromatographic system, and we designate it as the static-charging method.

An alternate charging method was used to simulate sampling of a dynamic gas system. In this method, krypton and/or xenon contained in a stream of nitrogen or helium were adsorbed on activated charcoal at −112° F. The tracers were subsequently eluted with the helium sweep gas with heating, and transferred to the column for separation. We designate this method as the dynamic-charging method. Tests were performed to characterize the adsorbent bed used for sampling the gas stream.

Xenon-krypton separation on charcoal columns was studied at 32° F and 70° F, at two helium flow rates (0.6 and 1.6 liter/min) and at a helium pressure of 15 psia. The ratio of the flows was chosen to be proportional to the ratio of the charcoal bed lengths. Initial experiments with individual tracers were followed by dual-tracer experiments.

In addition to the separation studies, tests were performed on 2-in. charcoal beds proposed as retainers for the separated gas eluted from the columns.

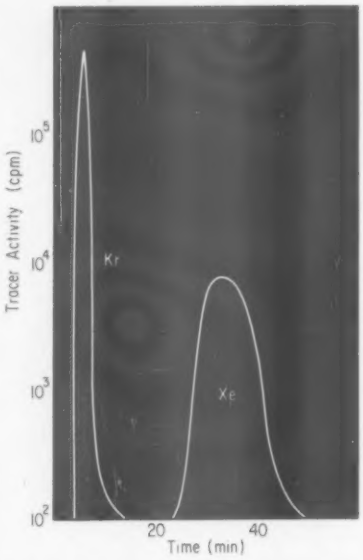


FIG. 4. SEPARATION PEAKS without normalization. Conditions: 32° F, 0.6-liter/min helium purge rate, 6-in. column length, dynamic charging

TABLE 1—Data for Xe-Kr Separation on Charcoal Columns

Tracer	*Column temp. (°F)*	*Column length (in.)*	*Helium flow rate (liter/min)*	*Charging method**	T_A *(min)*	T_P *(min)*	$T_{1\%D}$ *(min)*
Kr	70	16	1.6	Static	1.4	2.1	5.9
Xe	70	16	1.6	Static	17	20	26
Kr + Xe	70	16	1.6	Static	1.4 19	2.0 23	5.9 30
Kr	70	16	0.6	Static	3.3	5.5	22
Kr + Xe	70	16	0.6	Static	3.4 49	5.1 59	16 70
Kr + Xe	70	16	0.6	Dynamic	1.6 36	3.4 47	18 62
Kr + Xe	70	6	0.6	Static	1.4 15	2.2 18	4.5 24
Kr	32	6	0.6	Static	2.0	3.2	10
Xe	32	6	0.6	Static	38	52	>64
Kr + Xe	32	6	0.6	Static	2.0 39	2.8 46	5.3 59
Kr + Xe	32	6	0.6	Dynamic	4.4 23	5.4 33	6.3 48
Kr	32	16	1.6	Static	2.1	2.9	4.4
Kr	−112	2	0.6	Static	32	50	60
Xe	−112	2	0.6	Static	>300	—	—
Kr	−112	16	0.6	Static	250	~350	>450
Kr	−112	16	2cfm(N_2)	Static	2.4	4.0	15

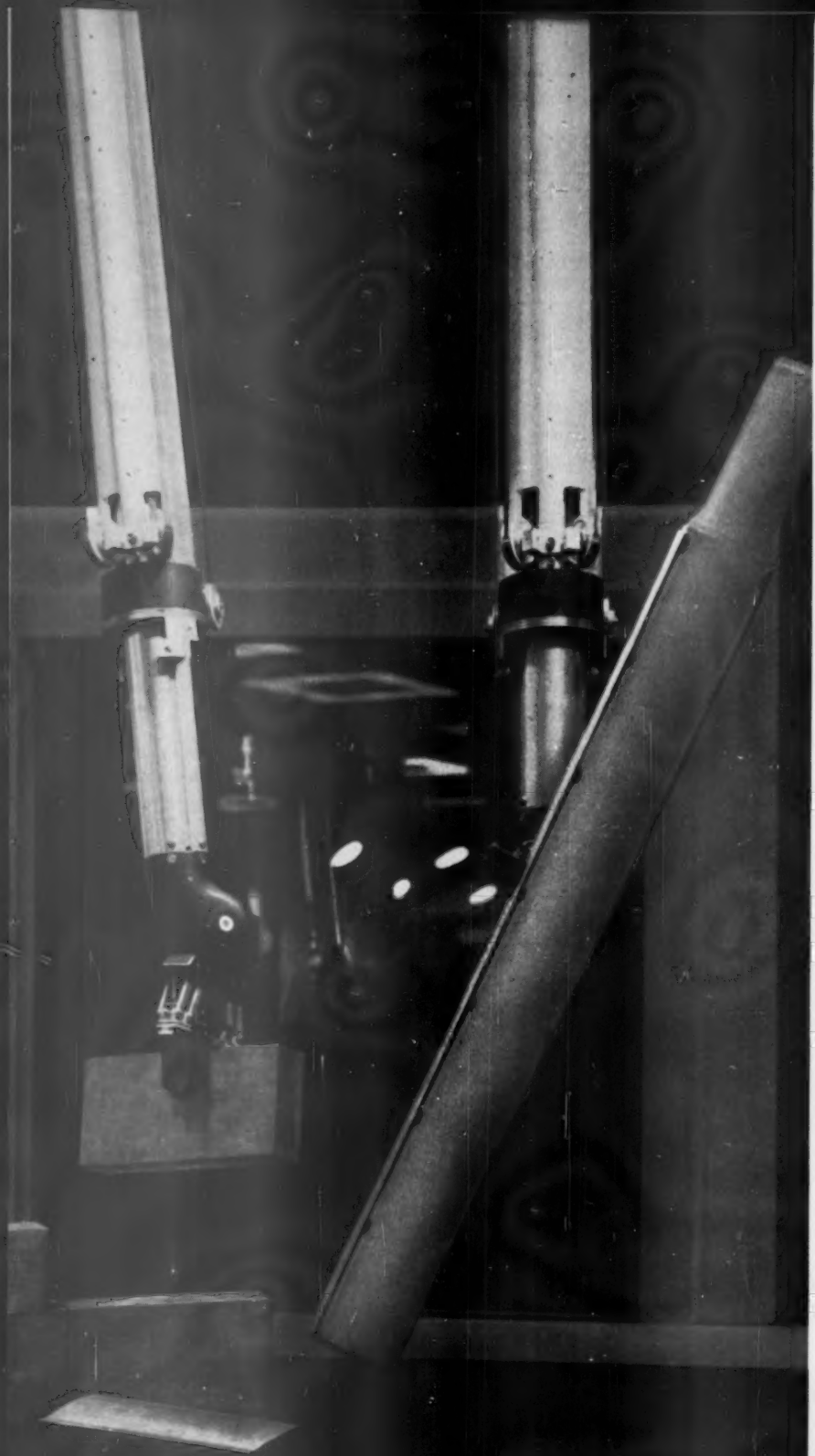
* Static charge: Tracers charged directly onto column with helium purge flow.
Dynamic charge: Tracers in nitrogen stream adsorbed on charcoal at −112° F, eluted with heating and passed to column with helium purge flow.

Results

The elution curves, as obtained from the on-stream monitor, were corrected for detector background and normalized to unity at peak height to facilitate comparison. Figures 2 and 3 are typical normalized elution curves. Figure 4, a curve prior to normalization, demonstrates the separation more clearly. The elution curves are characterized by T_A, the elapsed time from tracer injection to initial elution from the column; T_P, the elapsed time to the maximum elution rate; and $T_{1\%D}$, the time required for the elution rate to decrease to 1% of the maximum rate. Characteristics of elution curves are given in Table 1. The results indicated well defined separation of the gas fractions.

Discussion

The reproducibility of the elution patterns is adequate to ensure quantitative separation of the two fractions. The degree of separation, as measured by elapsed elution time between gas fractions, increases with decreasing helium flow rate at the same column conditions, or with decreasing temperature at fixed column size and sweep



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This article starts on page 76

TABLE 2—Correlation of Xenon-Krypton Separation Data

Column temp. (°F)	*Column length* (in.)	*Helium flow rate* (liter/min)	C_{Kr}	C_{Xe}
70	16	1.6	4.2×10^2	4.4×10^3
70	16	0.6	3.9×10^2	4.5×10^3
70	6	0.6	4.6×10^2	3.6×10^3
70	Average		$(4.2 \pm 0.3) \times 10^2$	$(4.1 \pm 0.4) \times 10^3$
32	16	1.6	6.0×10^2	
32	6	0.6	6.0×10^2	1.0×10^4
32	Average		6.0×10^2	

rate, or with increasing column length at fixed temperature and flow rate.

Results obtained with the dynamic charging method tended to deviate somewhat from those with static charging. It is thought that these differences are due to the relatively poorly defined injection times and to the higher temperature of the gas reaching the charcoal column with dynamic charging. This charging method is still being investigated.

A method of correlating ion exchange chromatographic separation on a quantitative basis (*8*) is based on a plate theory of chromatographic processes (*9*). The column is assumed to consist of a series of plates (i.e., unit volumes in which equilibrium distribution of the solute exists between the liquid and solid phases). The distribution coefficient, C, for the solute is given by

$$C = \frac{S_{n,p}}{L_{n,p}} \qquad (1)$$

where S = the fraction of the solute on the solid adsorbent, L = the fraction of the solute in the liquid, and p and n identify the number of theoretical plates and the number of solution volumes, equivalent to one plate, which have entered plate p. For any solute (*8*)

$$C = F_{max} \qquad (2)$$

where F_{max} = number of solvent column volumes that provide the maximum rate of solute elution.

Since the separation processes for ion exchange and gas chromatography are analogous, an attempt has been made to correlate the xenon-krypton separation data using this method. For this purpose, S and L in Eq. 1 are defined as the equilibrium fractions of the trace gas in a given plate adsorbed on the charcoal and in the helium phase, respectively.

Values of F_{max} for xenon and krypton in the various separation schemes have been estimated from the weights of charcoal in the columns from free gas volumes calculated assuming that the effective density of the charcoal is unity and from measured helium flow rates and T_p. Calculated values of C for several separation conditions (Table 2) appear to be independent of flow rate and column length and to increase with decreasing temperature.

Tests at −112° F demonstrated that 2-in. traps will quantitatively retain separated fractions eluted from the column, since the trap retention time for xenon or krypton is substantially longer than the quantitative elution time.

Additional studies are in progress to develop more rapid separation and assay methods for very-short-lived fission products in gas streams.

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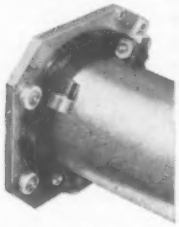

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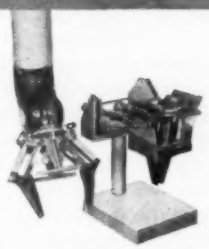

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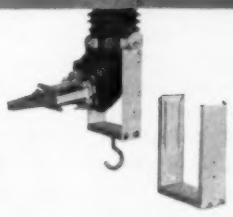
Improved *handle:* More rugged, more satisfactory control of separation indexing and squeeze motion lock.



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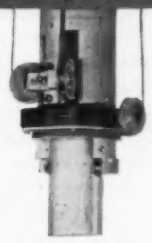

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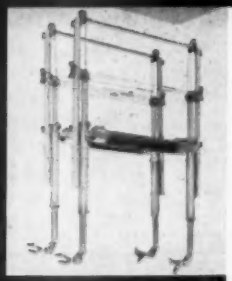

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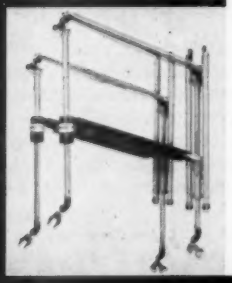

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Selecting Instruments for Organic Reactors

Reactors cooled by an organic fluid feature low pressure and conventional materials. Thus, standard industrial process instruments can give reliable, accurate and inexpensive measurements of flow, pressure and liquid level in organic moderated reactors. Still, the 200–300° F melting point of the terphenyl mixture planned for the Organic Moderated Reactor for Piqua, Ohio, requires that we select and install process instrumentation carefully.

Measurement and instrument installation methods for the 11.4-Mwe OMR have been proven by Atomics International in operating the OMRE in Idaho for several years and in quarter-scale prototypes of the OMR purification and degasification systems that have operated for more than a year at Canoga Park, California. OMR's terphenyl mixture, which has a molecular weight of about 230, will be heated from 525° F to 575° F while being pumped through the OMR at the rate of about 12,000 gpm.

Calibration. To keep the stagnant terphenyl in instrument manifolds from freezing, temperature is maintained constant with pressure-controlled steam. Electrical heating could be used, but it costs more and makes control of final temperature more difficult.

Three steps are important to preserve instrument calibration:

1. Calibrate at the operating temperature to avoid marked span and range shifts beyond the range −20 to +200° F.

2. If an instrument is to be in and out of service often, put a thermocouple on the instrument body so the operator can be sure the instrument is at a consistent temperature when used at OMR operating temperatures—this will avoid effects of sharp shift of zero point, particularly above 250° F.

3. Cool the transducer portion with air (1 or 2 cfm usually suffices) to prevent overheating.

Also, if an instrument is to operate above 400° F it usually requires special bolts and gaskets to prevent leaks. With these common factors kept in mind, we can consider specific types of instruments used.

Flow measurement. Turbine meters serve successfully up to 750° F if the stream is free of damaging particles. Orifice plates and venturi nozzles coupled to differential-pressure transducers will be used in Piqua for measuring flows above 5 gpm; many transducers are suitable up to 350° F. But since the orifice would be too small to measure flows below 5 gpm, Piqua also will use variable-area meters, which serve well up to 750° F. When the meter has an armored metal tube with a magnetic follower to convert float height to an electronic or pneumatic signal, non-magnetic tubing must be used for the steam trace lines. Electromagnetic flowmeters find little use since the organic fluid has high resistivity and in-line temperatures are high.

Liquid level. Because installation is straightforward, displacement techniques (change in weight of a float), which will be used in Piqua, usually are better than a differential-pressure transducer. Slight calibration shifts occur when organic plates out of the vapor onto the float surface, but the transducer can be adjusted in service. The opaque terphenyl forces use of a blind gage glass with magnetic follower for readout; this device has been successful on vessels operating at 750° F.

Pressure. Measurements at high temperatures are made with a diaphragm-sealed pressure system when the process line connection is long enough to keep pulsation-induced fatigue from failing the diaphragm. As a filler material, silicone oil serves up to about 600° F and will be used in Piqua; NaK-filled transducers operate well and with accuracy within 1% of full-scale span up to 1,200° F. Extreme care is required to fill the seal and capillary and bourdon tubes properly.

Vacuums to 22 in. Hg can be measured reliably with a diaphragm-sealed system if head errors are avoided by placing the diaphragm connection, capillary tubing and transducer at the same elevation.

Temperature. Measurement of process temperature does not present any problem since the temperature-measuring element is inserted in a conventional thermowell.

Control valves. Since some slight leakage is tolerable, it usually is satisfactory to use a teflon stuffing box with a cooling fin. But in a vacuum system, where leakage is intolerable, a bellows-seal valve is essential. To keep the organic molten so it will not cause the bellows to fail when moved, it is essential to steam trace the outside of the stuffing box.

From "Organic Reactor Process Instrumentation," by David J. Sobo of Atomics International, presented in San Francisco at the May, 1960 Conference of the Instrument Society of America.

New Aluminum Alloy for EBWR Cladding?

Tests, including exposure to 18-ft/sec water, demonstrate that a newly developed aluminum alloy (tentatively designated Argonne 288) has corrosion resistance superior to the alloy X 8001. Present plans are to use it as cladding for ceramic fuel pellets in the next EBWR core.

The alloy composition, which came out of the Al-alloy-development program at Argonne National Laboratory, includes 1% nickel, ½% iron and 0.1% titanium. A critical factor for minimizing corrosion is to keep silicon content to a maximum of 0.002%.

Good high-temperature-strength properties can be achieved by powder-metallurgy fabrication techniques. At 660° F, a powder-metallurgy alloy of A288 composition has ultimate tensile strength of 25,000 psi—comparable to zircaloy and a factor of 10 better than alloy X 8001.

In a 235-day corrosion test in 660° F water, wrought A288 corrosion was 0.3 mil/yr; X 8001 corrosion was >3 mil/yr. With dummy X 8001 fuel elements in the EBWR grid, the crud formed has analyzed 36% Al. It probably will be less with the more resistant alloy 288.

A 2,000-lb commercial melt has been successfully produced by Aluminum Foils, Inc. Experimental A288 spike elements in EBWR will provide in-pile information.

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Properties of Coolant Gases

Gas	Density* $\rho(10^{-4}$ gm/cm^3)	Specific heat, C_p (cal/gm °C)	$\rho^{-2}C\rho^{-2}$	Pumping power relative to H_2	Viscosity η c.p.	Thermal conductivity (10^{-4}K cal/cm sec °C)	Thermal-neutron abs. cross section σ_a (barns)
H_2	32	3.53	2.2×10^5	1	1.7	9.0	0.33
He	63	1.24	1.3×10^6	5.9	3.8	6.5	0.007
N_2	44	0.265	2.8×10^6	12.5	3.4	1.26	1.88
Air	46	0.261	2.7×10^6	12.0	3.5	1.33	1.88
Ar	63	0.125	1.3×10^7	58.1	4.5	8.6	0.62
CO_2	69	0.277	9.9×10^5	4.5	3.25	1.30	0.0036

* At 500° C and 10 atm.

Hydrogen as a Power Reactor Coolant

By DOUGLAS BRADLEY, *U. K. AEA Atomic Energy Research Establishment, Harwell, England*

A hydrogen-cooled reactor is economically desirable and structurally feasible. But it will be safe only if we can guarantee to keep the gas purity in excess of 97% H_2 at all times and in all places. As with most safety arguments the feasibility of providing such a guarantee cannot be assessed numerically; however, some guide is given by experience in industries that handle hydrogen. The chemical industry has handled hydrogen safely for a number of decades at higher pressures and temperatures than those considered for reactors; standard gas-circuit components are used—no special equipment or separate design standards are necessary.

Hydrogen often is considered the ultimate gaseous heat-transfer medium —it is not. The higher molar specific heats associated with a more complex molecular structure make hydrocarbons more attractive for heat removal. Unfortunately, the complex molecular structure also creates chemical instability under reactor conditions; of the *acceptable* gas coolants hydrogen is easily the best for heat transfer. This advantage of hydrogen has led to appraisal of its engineering, chemical, metallurgical, and nuclear aspects as they might contribute to an economical reactor. But these factors have been overshadowed by handling problems.

Handling Hydrogen

Hydrogen can be a difficult gas to handle. Small molecules give it ability to diffuse through metal walls and to effuse faster through leaks than any other gas. And out-leakage of hydrogen or in-leakage of air can create fire and explosion hazards.

Leakage. Leakage through circuit defects would be ~40,000 ft³/day (~200 lb) if molecular effusion and defect sizes are equivalent to those experienced with Calder Hall reactors. By comparison leakage by diffusion (~100 ft³/day or <1 lb/day) would be trivial compared with leakage from circuit defects. 40,000 ft³, equivalent to a loss of nearly 10%/day, would be unacceptable on safety and economic grounds. Thus design standards for a hydrogen circuit would have to be better than for CO_2 reactors but we do not consider that reduction to 1%/day to be impracticable.

Transportation and storage. This amount of leakage might necessitate large volumes in reserve. If so, bulk transport and storage of high-pressure cylinders would not be feasible for the quantities (~2-million ft³) envisaged for a four-reactor station. Thus an on-site hydrogen plant and gasholders would be essential and would be considerably more expensive than an equivalent plant to provide CO_2; electrolytic production probably would give best over-all economy by using off-peak reactor power for the electrolysis.

Safety. Mixtures of hydrogen and air can "explode" or "detonate" if there is a source of ignition, or they can ignite spontaneously. But "explosion" is not explosive in the generally accepted sense of the word—it is characterized by smooth burning with a low-velocity flame propagation. Under reactor conditions (say 500° C and 10 atm) it would occur only if the hydrogen-air mixture were in the range 3–85% H_2 (*1–8*). Though not itself violent, if the combustion is allowed to reach thermodynamic equilibrium there would be large pressure increases that could cause vessel rupture. Figure 1

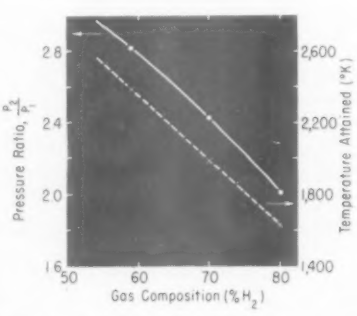

FIG. 1. EXPLOSION of H_2-air mixtures, where the initial conditions are 150 psi and 773° K

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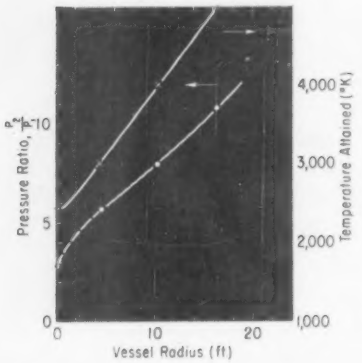

FIG. 2. DETONATION of H_2-air mixtures at upper detonation limit, where the initial conditions are 150 psi and 773° K and mixture is 59% H_2 by volume

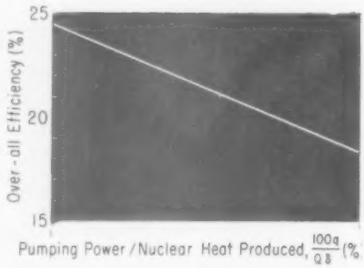

FIG. 4. HOW CHANGE IN BLOWER consumption affects over-all efficiency, where over-all efficiency = $[\eta\alpha(Q + q) - q/\delta]Q^{-1}$, η = fraction of turbine heat input converted to electric power = 0.25, α = fraction of heat-exchanger heat input converted to heat output = 0.98, δ = efficiency of blower = 0.75, q = heat equivalent of work done by pump, Q = rate of nuclear heat production

shows calculated pressure-temperature values for postulated reactor conditions (*8–9*).

"Detonation" is characterized by a shock wave maintained by the energy released in the combustion process. This limits the conditions under which detonation is possible to a narrower concentration range—18–59% H_2 at normal temperature and pressure (*10*). The need for energy release to maintain the shock wave means that detonation depends strongly on system geometry. It can propagate in one direction only and requires unobstructed distance in which to build up. The distance increases with increase in tube diameter; limited data indicate it would require very long lengths of straight pipe in a typical circuit before detonation could occur (*11*).

We can calculate pressures that result from detonation; Fig. 2 shows typical results for reactor conditions. Detonation pressures, which depend on vessel size, can be very much higher than explosion pressures. Also, the value P_2 in the pressure ratio is now the pressure immediately behind the detonation wave. The pressure felt by a plane surface normal to the direction of propagation is higher, $(P_2 - P_1)$ V_1/V_2, where V_1/V_2 is the ratio of the specific volumes of the gas in the unburnt and burnt states. For example, the pressure felt by the wall at the end of a 4.5-ft-dia tube under the conditions shown in Fig. 2 would be 1,130 psi, i.e., P_2/P_1 is increased from 5.7 to 7.5.

"Autoignition" occurs under almost any conditions if a mixture within the explosion-concentration range exceeds a certain temperature. Limited data indicate this temperature is 400° C in the absence of catalysts (*12*). Thus, in the reactor explosive concentrations must be avoided since ignition inevitably would follow.

We must consider the combustion phenomena in relation to the design of a reactor-coolant circuit. No rational basis exists for the design of pressure vessels to withstand explosion or detonation. The situation is complicated by the possibility of multiplication of pressures by reflection, in which case peak pressures could be many times the equilibrium pressure (*9, 13*). Explosion-proof design of a reactor circuit would be uneconomic. It is only economic for smaller and more compact systems, such as hydrogen-cooled alternators and generators.

To overcome this difficulty we would have to be able to guarantee that explosions could not occur—to ensure that at all times and in all places the concentration would remain outside the explosion limits. This is the practice adopted by the chemical industry, where freedom from air inleakage is ensured by maintaining all parts of the gas circuit above atmospheric pressure. Provision also must be made for purging the circuit with an inert diluent on charge and discharge of the hydrogen; CO_2 probably would be used. Also we would need to monitor and purify the hydrogen continuously.

This need for positive pressure in the hydrogen circuit and the large leakage transfers the ignition problem to the outside of the circuit. Here ignition can be prevented by proper ventilation and arrangement of electrical equipment. Still, building design could prove to be a major problem; it is highly likely that locating a hydrogen-cooled reactor outdoors would prove least hazardous.

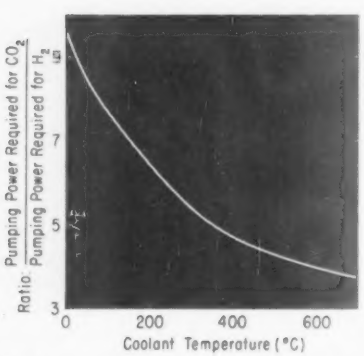

FIG. 3. PUMPING-POWER COMPARISON for hydrogen and carbon dioxide coolants assuming constant heat output, coolant temperature rise and fuel-element-surface temperature ($\rho^2C_p^3$ comparison)

Engineering Economics

Quantitative comparison of gas coolants is difficult because changing coolant-channel geometry to optimize heat-transfer performance for each gas also changes nuclear performance. Thus it is important to design the reactor core to fit the particular gas properties—a simple generalized comparison is not possible. Still, pumping power needed for various gases gives a simple guide. For circumferentially finned fuel cans, pumping power is proportional to $\rho^{-2}C_p^{-3}$ (where ρ = gas density and C_p = specific heat at constant pressure) for reactors in which heat output, coolant temperature rise, maximum fuel-element-surface temperature and flow area do not vary (*14*). The relationship also holds for other fuel elements where profile drag predominates over frictional drag; thus it would apply to the shorter and thicker fins or mere surface roughening required for hydrogen. Figure 3 compares hydrogen and carbon dioxide on this basis; Fig. 4 shows resultant savings in over-all efficiency for typical circuit parameters (*15*).

Power consumed by a blower reappears as heat in the coolant. Thus increase in pumping power increases the reactor heat output at the same time as it decreases efficiency; there is an optimum value that gives maxi-

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This article starts on page 84

mum electrical output (5–10% for CO_2). But since larger blowers cost more the economic optimum is about 2–4% for CO_2; it probably would be only 1–2% for hydrogen. This economic optimum means that full advantage could not be taken of the theoretically possible lower blower needs with hydrogen. Still, the reduction would be accompanied by a substantially higher electrical output, which would reduce the capital cost per kilowatt.

Material Compatibility

It is important that hydrogen not react with and weaken the reactor materials. Also, reaction products transported around the coolant circuit could complicate shielding requirements.

Reaction with graphite. Thermodynamic conditions in a hydrogen-cooled reactor favor buildup of methane to high concentrations in the circulating gas. But the reaction rate is very low and the graphite weight loss and mass transfer of carbon around the coolant circuit would not be serious. Possible catalytic and impurity effects need further investigation (*16, 17*).

Reaction with fuel elements. The ready formation of low-density hydrides with metallic uranium would accentuate attack if the cladding should rupture. But inert compounds such as uranium dioxide or uranium monocarbide would be suitable (*18*).

For an advanced gas-cooled reactor system with temperatures greater than 500° C and ceramic fuels the choice of cladding material is limited to stainless steel or beryllium. Both are basically inert to hydrogen, but radiation effects might need further study.

Reaction with structure. Embrittlement of steel structural components by hydrogen can be considered under two headings—physical embrittlement and chemical attack (*19*). Physical embrittlement is not observed above ~200° C; since it is caused by hydrogen diffusion and accumulation at grain boundaries, it depends on the amount of hydrogen dissolved in the metal—and hydrogen solubility in steel below 200° C would not be sufficient to cause embrittlement. However, during reactor operation solubility could be high enough to cause trouble if the reactor shell is cold. Thus vessel cooling rate must be low enough to permit hydrogen release—less than 30–45° C/hr is specified for hydrogen plants in the petroleum industry.

Chemical attack is the form of embrittlement experienced at higher than 200° C. It results from decarburization caused by the hydrogen-carbon reaction. So a reactor shell must be protected during normal operation by using proper alloys. For example, 6% Cr, 0.5% Mo raises the temperature below which attack does not occur from 200° C to 610° C. Such alloys usually are available in pressure-vessel and high-temperature steels. Irradiation effects on both forms of embrittlement need further investigation.

Austenitic stainless steel is not prone to embrittlement but would be costly. But experience with pressurized water reactor systems shows that the increased cost is not prohibitive for large reactors where a high proportion of the cost goes into turbogenerator equipment and buildings.

Hydrogen coolant would be acceptable from a nuclear standpoint. Neutron capture would be higher than for CO_2, but this could be overcome by slight enrichment (say 1%). Induced activity would arise primarily from impurities present, and pressure loss would decrease reactivity, making the system fail-safe.

* * *

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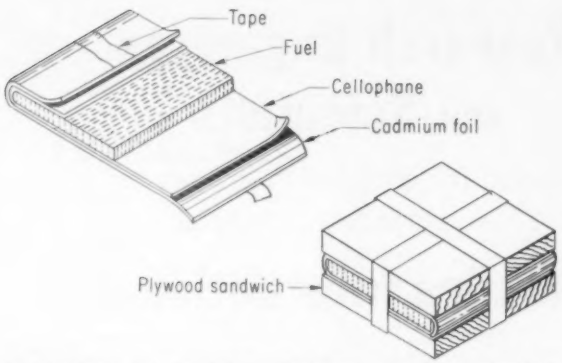
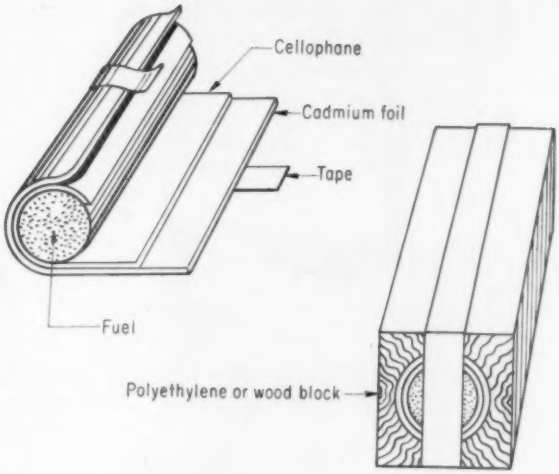


PACKAGING FLAT SAMPLE. Cadmium is neutron absorber; wood is hydrogenous moderator; cellophane prevents contamination



CYLINDRICAL SAMPLE. Cadmium-wrapped sample is placed in hole bored in moderator. Tape holds sample in position

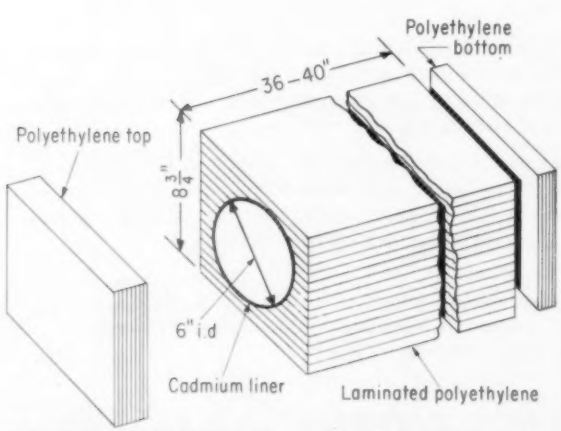
Safer Packages for Shipping Fuel

By W. B. LEWIS and R. W. GOIN, *Phillips Petroleum Company, Idaho Falls, Idaho*

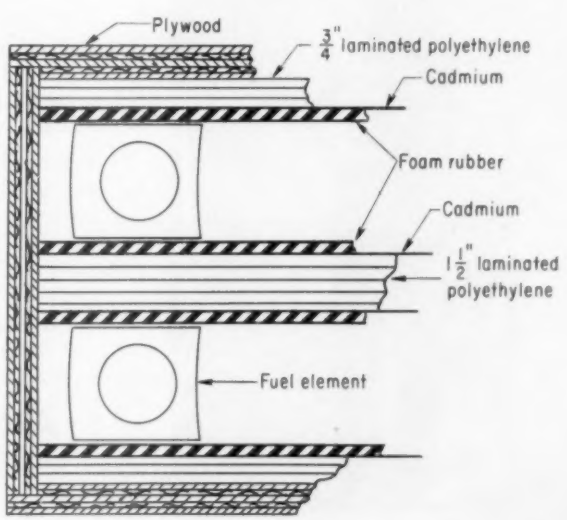
As long as it is possible for packaged units of fissionable material—each package safe in itself—to form a critical assembly when units are brought together, the hazard of inadvertent criticality will be a source of continual worry. No amount of written instructions clearly stating what procedure must be followed will relieve the worry—the person who places the last subcritical unit on the previously just-subcritical stack might not have read the instructions. We believe that true safety lies in designing containers that cannot, under any circumstances, nor in any numbers, be assembled into a critical mass—i.e., "isolated units."

An isolated unit is a subcritical configuration of fuel, moderator, and poison such that the neutron current vanishes at the boundary of the unit. Clearly there can be no interaction between isolated units. Most shipping and storage methods rely on spatial separation only, but isolation can be achieved readily by separating fuel-bearing regions by a poison-moderator-poison sandwich. In effect, fast neutrons originating in a fuel region pass through one layer of poison and are moderated before reaching the second layer, where they are effectively removed. The sandwich can be flat, rolled into a cylindrical shell, or otherwise formed to suit the circumstances. This approach eliminates restrictions on storing quantities of packaged fuels and reduces the space needed.

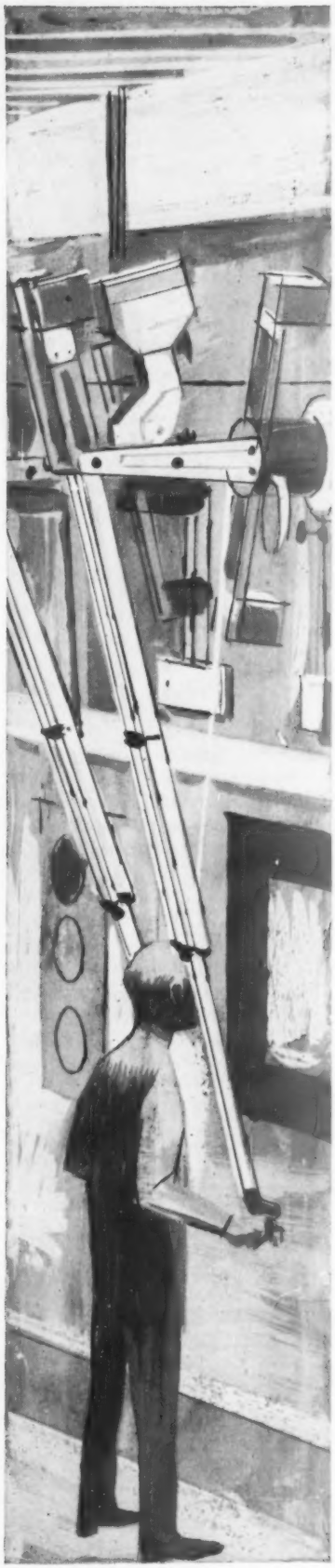
The proposed fuel-shipping sand-



FUEL-BOTTLE CONTAINER. Wood is too bulky for this use



FUEL-ELEMENT CONTAINER. Cadmium-polyethylene-cadmium sandwich separating fuel layers provides infinite safety



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This article starts on page 91

Safe Slab Thickness and Cylinder Diameter of "Criticalium"

Moderator thickness (in.)	*Slab thickness (in.)*						*Cylinder diameter (in.)*						
	With wood moderator of ρ=			*With polyethylene moderator of ρ=*			*With wood moderator of ρ=*				*With polyethylene moderator of ρ=*		
	0.2	*2.0*	*8.0*	*2.0*	*8.0*	*15*	*0.2*	*2.0*	*8.0*	*15*	*2.0*	*8.0*	*15*
⅛	0.32	0.04	0.02	1.4	0.04	0.02	0.70	0.16	0.80	0.02	1.4	0.70	0.16
¼	0.70	0.08	—		0.32	0.16	1.4	0.32	0.16	0.08		1.4	0.32
⅜	—	0.16	0.04		0.70	—		—	—	—			0.70
½	1.4	—	—		—	0.30		0.70	0.32	0.16			—
⅝		0.32	—		1.4	—		—	—	—			—
¾		—	0.08			—		—	—	—			1.4
⅞		—	—			—		1.4	—	—			
1		—	—			—			—	0.32			
1¼		—	0.16			0.70			—	—			
1⅜		0.70	—			—			—	—			
1½		—	—			—			0.70	—			

wich is of cadmium foil and solid hydrogenous material (wood or polyethylene). Water also can be considered as a sandwich filler because of canal-storage problems and because its properties are well known.

The sandwich thickness depends on composition and dimensions of the fuel region and on the hydrogen density of the moderator, which can be expressed as an equivalent water density. Wood has an equivalent density of ⅓ to ⅔; polyethylene, 1.2.

To provide a safety factor, our calculations were made with a fictitious fuel, "criticalium," which has a 750-barn fission cross section and no non-fission captures and which produces 2.98 neutrons per fission. Its effective density is assumed to vary from 0 to 17 gm/cm³. Criticalium would be more hazardous than either U^{235} or Pu^{239} with the same effective density. The table summarizes calculated safe dimensions for packaging. The calculations were made on an IBM-650 using a two-group two-region code. All simplifying assumptions were conservative.

We believe that there is no reason, from the viewpoint of nuclear safety, why small samples so packaged could not be transported by any means, without special shipping instructions. The same principles apply to compact storage of fuel in a canal or storage vault and also might be adaptable to fuel processing plants.

* * *

For detailed description of calculations, see Safe Packaging for Shipping and Storing Fissionable Material, W. B. Lewis, R. W. Goin, IDO-16536 (1959).

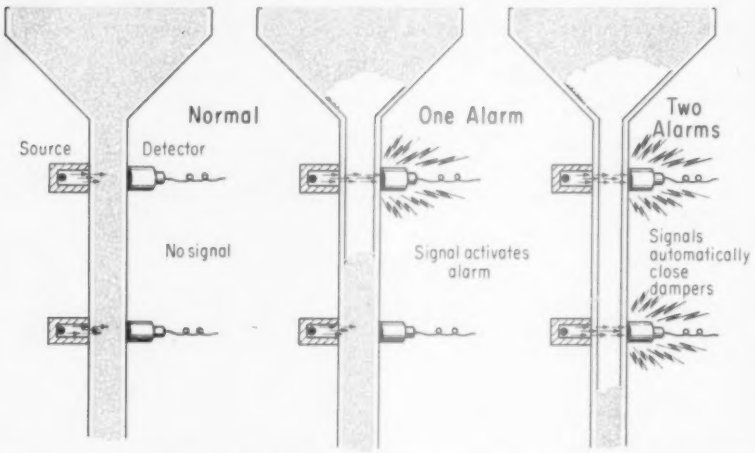
Measuring Fuel-Cluster Metal and Water Volumes

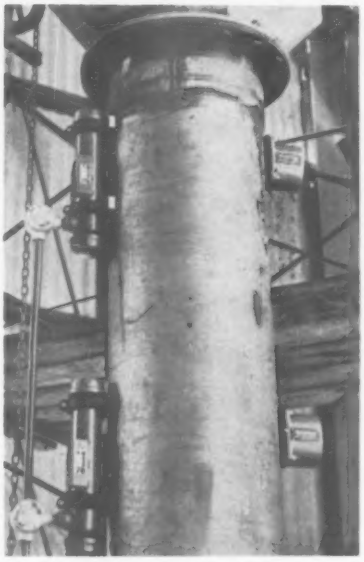
The accuracy previously required at Bettis in measuring metal and water volumes in fuel clusters was ±½%. This could be met by measuring displaced-water overflow from a tank and by filling the component with measured quantities of water. Requirements, however, are now stricter—±¼% accuracy.

The method developed to meet the new requirements (reported by J. M. Dickson et al.) measures water height in a tank by means of a transistorized-relay circuit. The circuit is closed when the rising water level touches a needle, turning on a signal light. To prevent overshooting the contact point, a second needle in the probe, 0.002 in. behind the first, is connected to a warning light.

Uncertainties in measuring the miniscus and spillage contributed to the inaccuracy of the earlier method. Another disadvantage was the 8–12 hr needed to measure a cluster.

With the new method, a cluster can be measured in about 1 man-hour with an accuracy of 0.28% or better. The uniformity of the acrylic-plastic water tank exceeds that necessary for the accuracy of the method.





GAGES SHOW THREE CONDITIONS IN COAL PIPE: normal flow, no signal; one "No-Coal" signal, start vibrators to restore feed; two "No-Coal" signals, close dampers before fuel fails and cold air from blowers causes thermal shock. Photograph at right shows how detectors (at left) and sources (at right) are installed on vertical coal pipe

Gamma Gages Solve Coal-Clogging Problems

Boiler operators at Coshocton, Ohio, are resting easier these days because gamma gages are watching feed pipes in which coal clogging is sometimes a difficulty. In normal operation the coal is crushed and carried up to hoppers from which it descends to cyclone boilers below. When the descending coal clogs, two distressing things happen. First the boiler runs low on fuel. If this difficulty is not quickly corrected, a rush of cold air from the still running blowers may cause a damaging thermal shock.

The drawing shows how Industrial Nucleonics has solved the problem with two AccuRay level-gage installations. In normal operation there is coal between each source and its detector. If a blockage occurs (either a bridging of coal in the hopper or a plug in the pipe near the upper gage), a signal from one gage shows that trouble is on its way. The operator, who is always on hand because of additional duties, responds by activating vibrators that usually dislodge the stuck coal. If they fail, he shuts the dampers to cut off air flow. If *he* fails and both gages give a "No-Coal" signal, the system automatically cuts off the dampers before fuel ceases to flow into the boiler and allows a rush of cold air.

In the photograph are shown two sources and two detectors installed on a vertical pipe. Each source has 0.5 mg of 1620-yr radium; each detector houses an infinite-life, halogen-quenched, stainless-steel-shell G-M tube, a relay with 3-amp contacts and a thyratron gas-filled tube to close the relay.

Nuclear-Battery-Powered Timer

Timers are often the weak and difficult links in engineering designs; in Arctic snow they freeze; in rockets they fail with overheating. But a long-lived nuclear-powered timer, recently announced by Radiation Research Corp., dodges these difficulties and offers 1% accuracy for intervals varying from minutes to years. You can also have intervals shorter than a minute, but accuracy is not quite so good.

RRC has long been a builder of nuclear batteries (NU, Dec. '53, p. 42; May '59, p. 199), and many of its most interesting products are outgrowths of nuclear-battery research: the timer, very thin dielectric films, small-current diodes and tritium-impregnated foil.

The timer has a nuclear battery charging a capacitor. When a predetermined potential has been reached, a specially designed diode fires, delivering a pulse of energy from the capacitor to a load. Although the basic idea is old, the performance is new; precision and ruggedness come from better components and "a couple of gimmicks" about which the makers are willing to say only a little.

The diode must fire reproducibly at just the right potential difference. Since diodes that do so predictably are hard to find, RRC has developed its own. From the same development have come voltage-regulating diodes that require as little as 10^{-10} amp for proper regulation.

Nuclear batteries made at RRC are all of the beta-collection type; beta particles pass through an insulator and accumulate on a collector electrode. The present Kr^{85} battery delivers 10^{-10}–10^{-8} amp at ~3,000 volts. Under development for the AEC is a Ce^{144} battery using vacuum as a dielectric. It may sound difficult, but remember that in outer space a hole in a vessel is a vacuum pump. The AEC program involves demonstration of a 250-kv, 1-watt, 2,000-curie prototype and design of a 1-kw model.

From early battery projects came the company's only present large-quantity product (tritium-impregnated titanium foil for accelerator targets and ionization sources) and the company's most promising development for the future (thin dielectric films: 1–2 microns of Teflon or other polymers with resistivities as great as 10^{18} ohm-cm).

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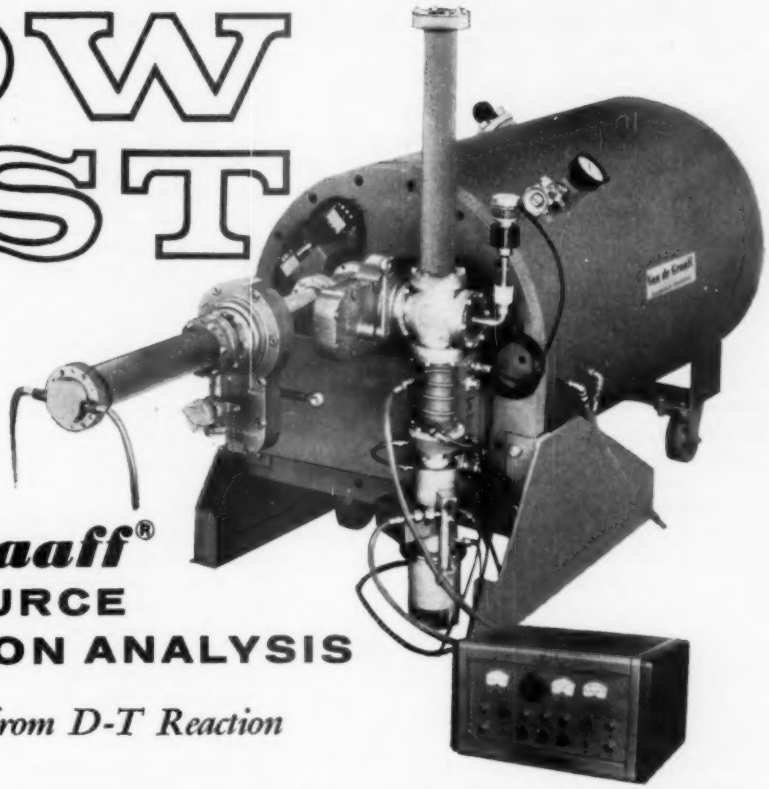

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Precise Tracer Measurements of Liquid and Gas Flows

By COLIN G. CLAYTON, *Isotope Research Division, AERE, Wantage, Berkshire, England*

Radioactive-tracer methods for measuring liquid and gas flow rates are gaining increasing importance because they offer small cost and great accuracy and convenience. We have recently made a series of tests to see how accurately we can measure flow rates. With liquids we use both dilution and velocity techniques. Direct comparison with the standard at the National Engineering Laboratory, Glasgow, shows that accuracy of radionuclide methods is as good as those of nonradioactive analogues and other flow-measurement methods. With gases the dilution technique presents too many difficulties; we limit ourselves to velocity measurements.

The reader will find it interesting to compare radioactive methods for measuring flow with other methods listed in Table 1.

FIG. 1. TEST MEASUREMENTS of liquid flow were conducted at Britain's National Engineering Laboratory

TABLE 1—A Comparison of Methods of Flow Measurement

Method	*Accuracy (%)*	*Operating range*	*Comments*
Current meters	±1–2	>2 ft/sec	Delicate. Requires calibration. Pipe diameter required. Continuous measurement for short time. No head loss. Proportional to velocity.
Pitot traverse	±2	>2 ft/sec	Tedious. Involves accurate traverse of pipe along a number of diameters. Diameter required.
Standard orifice plates	±1.5	No limit providing pressure difference can be monitored	Inexpensive. Clean fluids required. Large loss of head. Mostly used in smaller pipes (up to ~32-in. diameter—usually less). Continuous measurement.
Calibrated orifice plates	Up to calibration standard.		
Venturi flume	±1.5		Expensive, small loss of head. Can be used for "dirty" fluids. Continuous measurement.
Gibson method	±2	Determined by application	Pipe dimension along test section required. Involves emergency closing of pipe flow. Intermittent measurement.
Chemical dilution	±2	No limit	Intermittent measurement. No loss of head. Not dependent on cross-sectional area. Sufficient pipe length required to give complete mixing of an injected tracer. Not applicable to salt water.
Chemical velocity	±2	No limit	Intermittent measurement. No loss of head. Depends on knowing cross-section area. Sufficient pipe required for mixing. Not applicable to salt water.
Isotope dilution	±1.5	No limit	As for chemical dilution but much smaller injection volume required. Applicable to salt water.
Isotope velocity	<±1	No limit	As for chemical velocity but smaller injection volume required. Applicable to salt water.

Liquids

Our measurements with liquid flow used facilities at the National Engineering Laboratory (Fig. 1), where an absolute standard of comparison is available (*1–4*). The system includes a 20-in.-diameter pipeline, 700 ft long, in which flow rates as great as 20 cfs (cubic feet per second) can be measured to an accuracy of ±0.15% by direct weighing. Total capacity is >10,000 ft³.

Isotope Dilution

To measure liquid flow by isotope dilution one injects a tracer of known

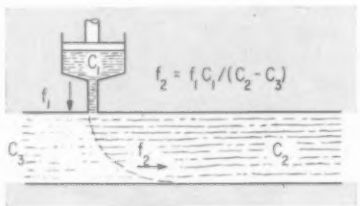

FIG. 2. ISOTOPE-DILUTION method for measuring flow. If f_1 is rate at which isotope is injected; C_1 concentration of injected isotope; C_2 isotope concentration at sampling point; C_3 its concentration before injection, the flow rate in the pipe, f_2, is given by formula shown

concentration at a known constant rate and measures the new concentration downstream after complete mixing has occurred (Fig. 2). An important advantage of the method is its independence of internal dimensions and variations in them. No previous calibration is required.

We have made experiments with Na^{24} as our tracer. Many other nuclides satisfy the main requirements, solubility and stability in the liquid. The user will choose the best one taking into account half-life, type and energy of emission, maximum permissible levels of radioactivity and available specific activity. If other things are equal, a beta emitter is preferable because with it problems of transport are minimal.

Injection and assay. Errors arise mainly during injection of tracer and assay of concentrations. For controlled injection we have made a special pump (Fig. 3)—essentially a piston driven through an accurately ground cylinder by a synchronous motor. We use figures obtained from the electric-power authority to correct errors caused by variations in supply-mains frequency—usually not greater than 0.02%. Errors from variations in cylinder dimensions are negligible. A special filling technique reduces our greatest problem with the injector—small air bubbles on the greased cylinder wall. The final gross error attributable to the pump was <0.05%.

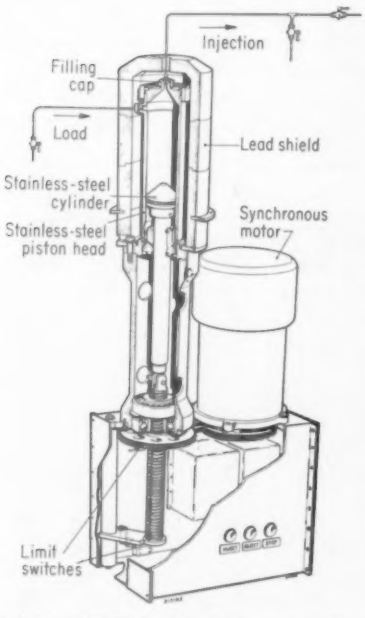

FIG. 3. INJECTION PUMP for isotope-dilution method injects at constant velocity

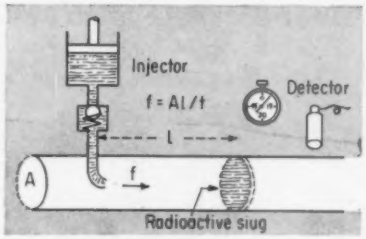

FIG. 4. PULSE-VELOCITY method relies on rapid injection of slug of radioactive liquid, measurement of its transit time

But our greatest source of error has been variation during assay, both statistical and instrumental. In practice the need for a planned counting program with regular background and reference counts requires a minimum of 5 min per sample. In our early tests we needed 15 min to obtain a standard deviation <0.3% (*1, 2*). This length of time was caused by the recirculation; we had to limit the activity of each injection so that the concentration in the system would not become great enough to interfere with later assays. Because this handicap is imposed by recirculation, we feel that our quoted errors are maximal; they can be reduced in practical measurements on nonrecirculating systems.

In Table 2 are the results of measuring 120 samples in two series of measurements at 5 and 20 cfs. We took samples from two points 110 and 220 diameters downstream from our injection point where strong experimental evidence indicates complete lateral mixing. A tear in a piston seal caused a consistent error in our first experiment. The results of the second are within the accuracy quoted for the salt-dilution method in a similar investigation on the same pipeline (*5*).

Velocity Method

Since internal dimensions of the pipe are required, the pulse-velocity method (Fig. 4) is not as generally applicable as the dilution method. In practice however, important differences between the two techniques suggest that in some circumstances the velocity measurement is better than dilution. Inaccuracies in pipe cross section excepted, errors are most likely to come from injection and numerical mistakes in analyzing results.

The method relies on a rapid injection of a small volume of radioactive liquid, which disperses as it moves along with the flow. At a stationary downstream detector the curve of counting rate as a function of time is asymmetrical, the amount of asymmetry decreasing as the distance from the injection point increases. Thus two detectors at different distances from the injection record curves of different amplitudes, lengths and symmetries.

So that the spread of the tracer charge at injection shall be negligible compared with that caused subsequently by turbulence, the injection should be a rapid radial one with force enough to spread the tracer across the pipe. The more nearly this ideal can be obtained, the shorter is the length of pipe required for accurate measurement. Here the velocity method has an advantage over the dilution method: it is easier to get a short, sharp injection than a smooth, continuous one.

Injector. A spring-operated device, shown in Fig. 5, satisfies our requirements for rapid injection. Radioactive solution goes into a reservoir either by pouring through a side arm or by insertion of a glass ampoule into the side arm and breaking it with a striker. Each injection is ~1 ml.

The injector is operated as follows (Fig. 6): (A) raise cocking handle to engage trigger, (B) push down and turn cocking handle to compress main spring, (C) press trigger to release plunger and drive tracer out through injection valve.

Using fast photography we found

TABLE 2—Accuracy of Isotope-Dilution Method*

Experiment	*Sampling station*		*Over-all results*
	110-dia	*220-dia*	
1	−2.32 ± 1.9%	−2.95 ± 1.7%	−2.63 ± 1.5%
2	−1.25 ± 1.1%	−0.67 ± 1.4%	−0.96 ± 1.6%

* Numbers are percent error in flow as measured by isotope-dilution method and compared with weighing standard.

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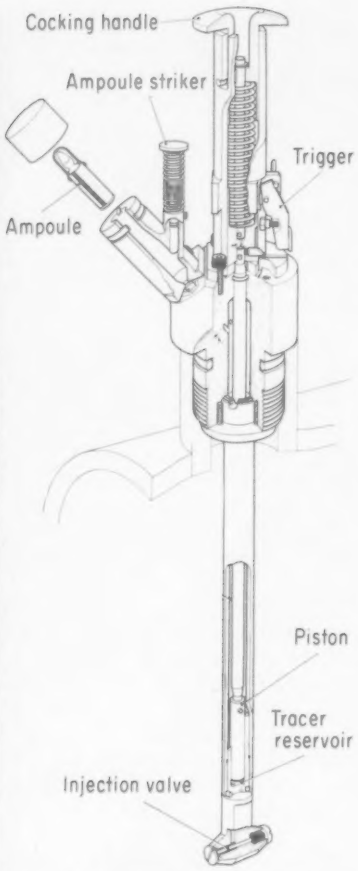


FIG. 5. INJECTOR for pulse-velocity method; operation is shown in Fig. 6

the injection time to be 14 msec, corresponding to less than 4 cm of travel in our 20-in. pipe at 20 cfs.

Timing. Measuring pulse velocity requires transit time between two points, and this in turn requires choosing an appropriate point on the counting curve that represents passage of the pulse. Although some say the peak is the best point (*6*), this choice does not take into account the effect of the laminar sublayer, that portion of the liquid close to the pipe wall. Moreover the peak is often ill defined. There is some evidence that Taylor's theory for choosing the peak (*6*) does not fit all available data, and there has recently been a suggestion that Reynolds' analogy, on which the theory is based, is not applicable to turbulent flow in pipes (*7*).

As a better point Whiteman chooses one that is midway between the ends of the segment in which counting rate is greater than 20% of maximum (*8*). Because the laminar sublayer and the method of injection affect the tail, he says that the tail should be neglected, and his method does so. The portion of the concentration-time curve between 20% points is almost symmetrical, and the halfway point can be taken as pulse center, most relevant to mean velocity.

The centroid of a pulse—that moment which divides it into two equal areas—is often taken as the reference, it being claimed that the centroid applies in all conditions of turbulence over the cross section of the pipe. Young and Wilson support this selection by comparison with direct weighing (*9*). They use the radioactive-pulse system we are describing and show that the centroid gives more consistent results than the peak.

Results. In our experiments, rapid injection, the large distance to the detector and large Reynolds numbers ensure that results are independent of variables in the injection and dependent only on our methods of analysis. Flow rates from four different experi-

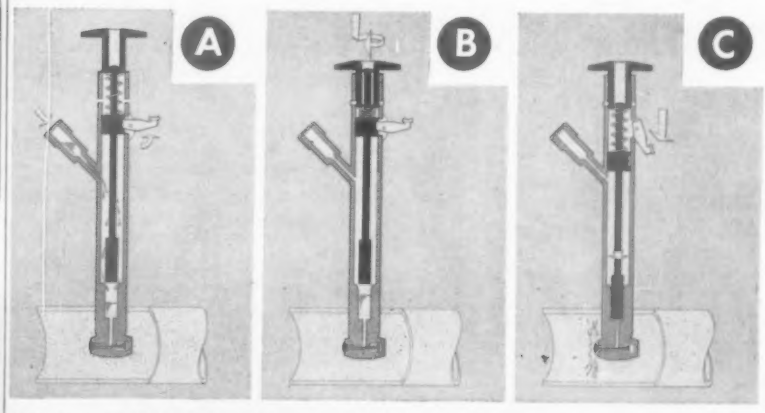


FIG. 6. INJECTOR OPERATION starts with (A) engaging trigger; then (B) main spring is compressed and (C) trigger is pressed, releasing plunger and injecting tracer

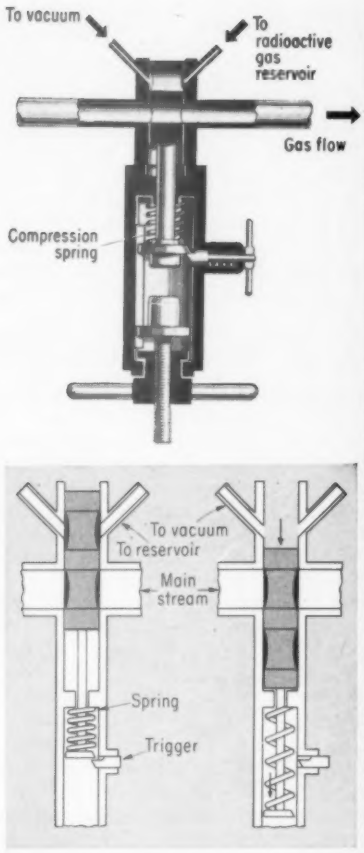
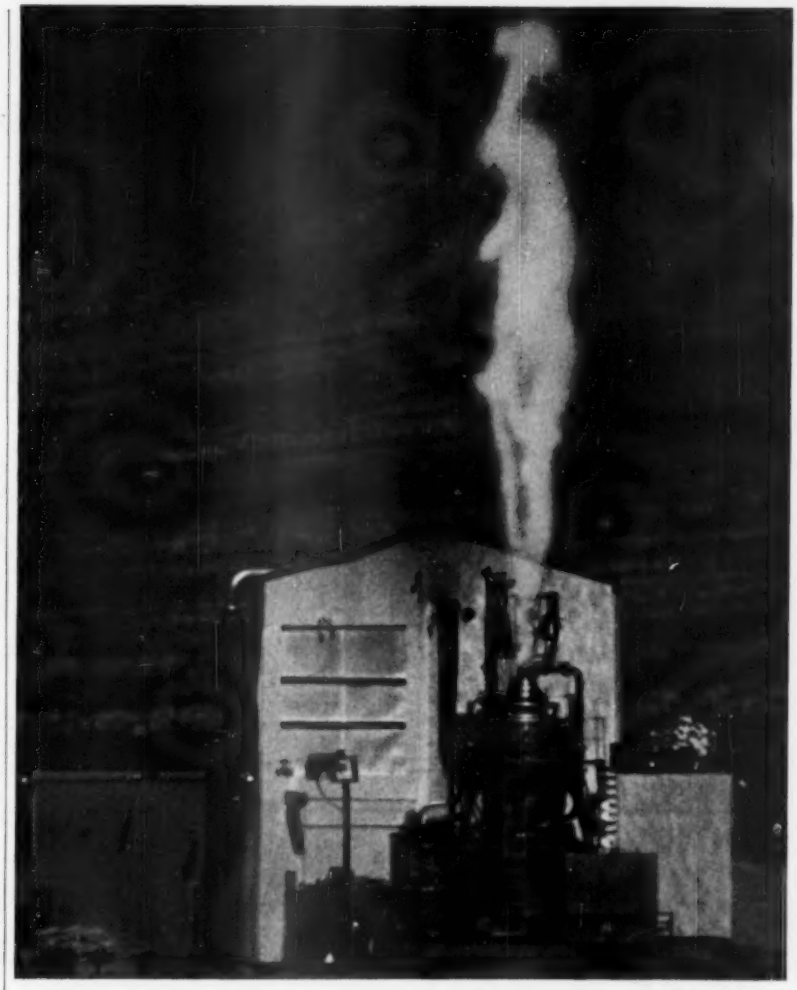


FIG. 7. GAS INJECTOR (top) provides rapid injection by mechanism shown (bottom); releasing trigger lets spring drive tracer-filled injection chamber into main stream, replacing dummy section that is usually there

ments at two velocities, each determined with four different characteristic points, give agreement within 0.2%, which we take as our limit of error.

In Table 3 we quote five groups of results representing 114 injections. Some were determined with two methods: by measuring the transit time between two detectors and by measuring the time between injection and arrival at the first detector. Since our experiments were designed to obtain information applicable with asymmetrical pulses, we quote the results in which the centroid was our reference point. Another reason for this choice is that it offers the possibility of a direct-reading instrument such as that of Leslie and Hunter (*10*) for direct digital indication of transit time.

Maximum deviation of the mean of any group from the flow measured by weighing was never greater than 0.44%, which is very satisfactory since the estimated error in pipe volume is



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±0.25% and that of the weighbridge is ±0.15%.

Gas Flow

Although water-flow techniques apply in principle to gas-flow measurement, problems with gas are more difficult. There are incentives to solving them, however. For example, successful methods will enable measurements of fast flow, transit and retention times in blast furnaces and contaminated-gas flow in coal-gas plants. Like Kniebes, Burket and Staats in their measurements of natural-gas flow (*11*) we have chosen a pulse-injection technique. But we differ from them in introducing our tracer, Kr^{85}, at pipe pressure so that large injection velocities do not contribute to initial dispersion of the charge.

The main points of comparison between liquid and gas measurements are these:

- Sampling for the dilution method is more difficult with gases. Consequently we have limited our efforts to the velocity method.
- Velocity of linear flow with gases is usually hundreds of times greater than with liquids. Typical ranges are 0.1–10 ft/sec with liquids and 10–1,000 ft/sec with gases.
- Tracers for gases are limited in number and in volume specific activity. Ar^{41} has often been used (*11*), but its short half-life (1.82 hr) causes unusual difficulties of shipment and correction. We got our Kr^{85} (10-yr half-life, 0.67-, 0.52-Mev gammas) from the Radiochemical Centre at Amersham with specific activity of 50 c/liter at NTP. Using it requires access to the inside of the pipe; we use a plastic-scintillator detector and feed the output through a 100-μsec time-constant circuit to a cathode-ray tube.

We also considered Br^{82}-labeled methyl bromide. (Br^{82} has a 35.9-hr half-life and emits 0.55-, 0.77- and 1.04-Mev gammas.) But the available specific activity, 110 mc/liter, is much smaller than that of Kr^{85}.

- Compatibility criteria change from solubility and stability in liquids to density and viscosity in gases.
- Compressibility of gases requires a special injector.
- Pipes for gases are usually much smaller than those for liquids.

Injector. Because gas is compressible, the usual method of injecting a tracer charge, forcing tracer under pressure through an orifice, is unsuitable for fast gas injectors. Compression ratios like 10 to 1, for instance, produce sonic velocities at release. Nevertheless some compression is tolerable if the orifice is directed radially or if one is making straightforward determinations in long pipes as in natural gas transmission (*11*).

Our injector, shown in Fig. 7 on p. 99, provides rapid injection without precompression. To inject tracer one releases the trigger; a heavy spring drives a tracer-filled injection chamber into the main stream, substituting it for a section that is normally there. In preparation for such an injection, the injection chamber is removed from the main stream, evacuated with an aspirator and filled from a reservoir much larger than the chamber. We can insert the 3-ml chamber into the gas line in 1–2 msec.

Results. We have tested our method by injecting 30–70 mc of krypton into a 1-in.-diameter pipe carrying gas at velocities up to 5×10^3 cm/sec (Reynolds numbers up to 8×10^4). Typical detector traces at distances of 2–6 ft from the injection show dispersion proportional to the 0.57 power of injector-detector distance (*12*); they confirm that Sjenitzer's calculations for liquid flow apply also to gases. With Sjenitzer's formula for dispersion and the observed sensitivity of our detector we drew up Table 4 showing limitations of this technique for pipe diameters and lengths. It shows that measurements involving up to 100 ft of 3-in. pipeline can be made accurately for Reynolds numbers as small as 2.5×10^4.

TABLE 3—Accuracy of Velocity Method

Experiments	*Flow rate (cfs)*	*Error (%)*	
		2-detector system	*1-detector system*
1–19	7.560	−0.34 ± 0.7	—
20–60	18.10	−0.44 ± 0.7	−2.87 ± 0.87
61–80	5.032	+0 060 ± 0.5	−1.53 ± 0.78
81–98	5.032	−0.38 ± 0.55	−1.63 ± 0.96
99–114	18.10	−0.27 ± 0.91	−2.54 ± 1.53

TABLE 4—Sensitivity of Gas Injection Method*

Reynolds number	*Distance downstream from injector (ft)*	*Pipe radius (in.)*			
		3	*2*	*1*	*0.5*
2.4×10^4	1	24.04	46.48	137.06	381.30
	10	6.50	12.52	37.00	103.24
	20	4.36	8.42	24.92	69.54
	40	2.94	5.68	16.80	46.86
	50	2.58	5.00	14.76	41.24
	60	2.32	4.50	13.32	37.16
2.4×10^6	1	188.2	349.0	920.2	2125.0
	10	55.2	106.2	311.4	853.2
	20	37.4	72.6	212.6	588.4
	40	25.2	48.8	143.6	399.6
	50	22.2	43.0	126.6	352.8
	60	20.0	38.8	114.2	318.2

* Figures are specific voltage output (volts per curie) from our scintillation counting-rate meter, but they can be taken as a relative scale. Our detector had a 2-megohm load. We used a 0.5-cm-thick, 1-in.-diameter plastic phosphor, an EMI 9542B photomultiplier and 3-ml injections of NTP krypton with a maximum specific activity of 50 c/liter.

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Melting Points of U-Binary Oxides

Prompted by a broader interest in interactions of UO_2 with other oxides in air, the melting points of binary mixtures of UO_2 and various oxides were measured. The mixtures were first heated at 800° C then briquetted, roasted at 800–900° C and pulverized; the procedure was repeated at 1,000–1,100° C and 1,200–1,300° C. Finally at 1,300° C, the procedure was repeated until the briquets showed no cracks and did not shrink.

Except for mixtures that melted during preliminary roasting, melting points were determined by cone deformation. The cone vertex was heated by carbon arc. Temperatures were measured with a micro-optical pyrometer. [S. G. Tresvyatskiy, V. I. Kushakovskiy, *Atomnaya Energiya* **8**, No. 1, 56 (1960)]

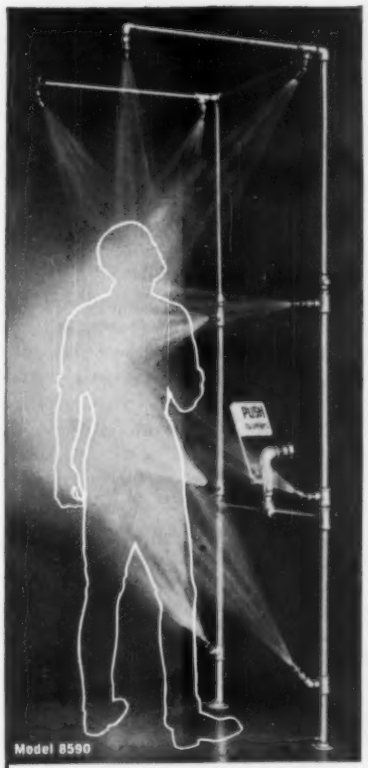
Composition (mol %)				
Charge		*U/Mc ratio from chemical analysis*	*Melting point (°C)*	*Mode of melting*
UO_2	*Other oxide*			
50	50 BeO	1/1.5	2,200 ± 50	Melts with difficulty, droplets
67	33 MgO	1/0.56	1,900 ± 50	Droplets form with difficulty
50	50 MgO	1/1.12	1,750 ± 50	Droplet formation
33	67 MgO	1/1.53	1,850 ± 30	Droplet formation
70	30 CaO	1/0.404	2,000 ± 50	Droplet formation
50	50 Al_2O_3		1,940 ± 30	Melts with droplet formation
50	50 SiO_2	1/1	1,770 ± 30	Surface melting
50	50 TiO_2		1,480 ± 30	Melts easily
50	50 ZrO_2		2,600 ± 50	Same as BeO
50	50 ThO_2			Does not melt in arc
50	50 V_2O_5		<800	Melted during preliminary roasting
50	50 MoO_3		900–1,000	Same as V_2O_5
50	50 WO_3		1,100–1,200	Same as V_2O_5
50	50 Ta_2O_5		1,850 ± 30	Melts easily
50	50 Bi_2O_3		1,800 ± 50	Melts little, evaporates strongly during heating
50	50 PbO_2		1,850 ± 50	Same as Bi_2O_3
50	50 SnO_2			Does not melt in arc, strong evaporation
50	50 Cr_2O_3		2,050 ± 100	Droplets form with difficulty
50	50 Fe_2O_3		1,370 ± 30	Melts easily
50	50 MnO_2		1,650 ± 30	Melts easily
100			2,700–2,750 ± 100	Difficult to melt

Sodium Oxide Cold Trap Tests

Experiments with cold traps of special design found that stainless-steel chips give a better filtering action than 0.5-mm-dia. wire mesh. The traps had sodium capacities of 30–50 l with an outer jacket of toluol coolant surrounding the sodium container. The toluol in contact with the sodium chamber evaporates and transfers its heat to water-cooled condensing coils at the top of the jacket. The investigators found that trap efficiency increases after some oxides have already been deposited and that trap capacity increases with flow velocity. Although the experiments got down to Na purities of only 20 ppm of oxide by weight, the authors feel that any required reduction could be achieved through proper adjustment of operating conditions. The experiments verified the following expression for oxide concentration

$$c(t) = c' + (c_0 - c')e^{-n}$$

where $c(t)$ is the oxide concentration after the trap has been operating for time t; c_0 is the concentration at $t = 0$, c' is the oxide solubility at the lowest Na temperature in the trap and n is the number of passes made by the total amount of sodium through the trap during time t. [P. L. Kirillov et al. Purification of sodium from oxides and methods of control of oxide content, *Atomnaya Energiya* **8**, No. 1, p. 30 (1960)]



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BOOKS

Radioisotope Techniques

By RALPH T. OVERMAN and HERBERT M. CLARK (McGraw-Hill Book Company, New York, 1960, 476 pages, $10).

Reviewed by J. F. BLACK, Esso Research and Engineering Co., Linden, New Jersey.

The Oak Ridge course in radioisotope techniques, which has served to train several thousand medical and research scientists in the use of isotopes, has at last been published in book form by two of the people most active in its development.

The book has been written primarily as a textbook with its material organized under ten major chapter headings. The first part of each chapter is devoted to a presentation of the theory of the subject, discussed in a form which should be readily understandable to a graduate or advanced undergraduate student in science. The last parts of the chapters are devoted to laboratory experiments. The authors have included more experiments than could be completed in a conventional semester course so that the instructor can have an opportunity to select on the basis of the interests of his students and in the light of the facilities he has available. These experiments have also been designed to keep reagent and equipment costs at the lowest level consistent with the experimental objectives.

The sketchy treatment of more recently developed isotope-measurement techniques involving the use of liquid-scintillation spectrometers or multichannel analyzers might be considered a shortcoming of this book. It might equally well be argued, however, that students are not likely to become involved with these more expensive assay procedures until some time after they have completed the course.

In addition to its value as a textbook, this publication should prove useful as a reference book to those who have already completed courses in radioisotope techniques. In addition to the descriptive matter, titles and figures in the text, the book contains 11 appendix sections, which give physical and mathematical information generally useful when working with radioisotopes. The chapters are followed by bibliographies, which are very complete up to 1956. After that date, the literature is not as thoroughly covered, but the most important references have been included either at the end of the appropriate chapter or in Appendix J at the end of the book.

A third use for this book will be for the education of technical people who desire to use tracers in specific applications under the guidance of a more thoroughly trained individual. The book can be used to familiarize such people with the technical background that is immediately related to what they will do and with the principles and practice of radiological safety. It can also be used as a source of selected experiments to train them in the laboratory procedures that will be involved in their problem.

Atomic Radiation and Polymers

By A. CHARLESBY (Pergamon Press, New York, 1959, xiii + 556 pages, $17.50)

Whether the addition of radiation to a polymer can yield a sum that is worth more than the cost of its parts is a question answered with a conclusive "Yes" by recent revelation of the process for making Cryovac L Film (NU, May '60, p. 122). There are many other questions about radiation and polymers: How do they affect each other? How can one influence the interaction? From experiments with them, what can we learn about the solid state, crystal structure, chemical reactions, etc.?

If your subject is polymers or radiation or the two together, you probably have much to learn from this comprehensive volume. The author has been recognized, perhaps, as the leading authority on polymer irradiation since he began publishing material on it in about 1953. Here he starts with radiation units and takes us to radiation protection. On the way he deals with interactions between radiation and matter, sources (accelerators *are* included), the nature of polymers and effects within them. Several chapters are devoted to specific substances and how they behave under irradiation: polyethylene, rubber, silicones and many others.

In a subject that is moving as rapidly as this one, it is impossible to set down the definitive and final word. Judging from lists of references, one can infer that the author brings us up to about 1958. But for a thorough grounding in fundamentals and an introduction to sophisticated thinking, polymer and radiation scientists will find this book ideal. —HE

Geneva '58 Proceedings

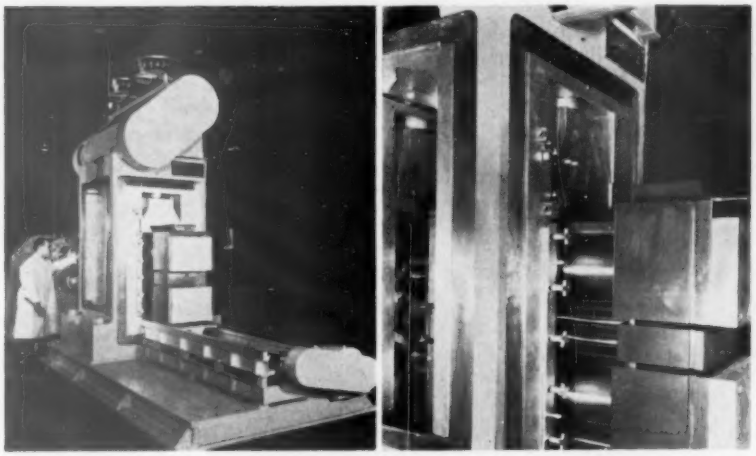
Other volumes have been described beginning with the July, 1959, NUCLEONICS. The Proceedings are published by the United Nations.

Vol. 7, Reactor Technology (844 pages, $19.50), includes sessions E-19, E-21 and E-22. Discussions vary from broad reviews of aqueous-homogeneous, liquid-metal and molten-salt systems to more specific considerations such as reactor chemistry and fuel fabrication. Graphite behavior is considered at length, and shorter sections are devoted to in-pile loops and detecting defected fuel elements. Other papers on fuels cover thermal conductivity, heat-transfer theory and design.

Vol. 13, Reactor Physics and Economics (635 pages, $18.50), includes sessions B-19, Reactor Physics and Shielding; B-15, Fuel Cycles; and B-14b, Economics of Nuclear Power. Among the topics in B-19 are reactor-shielding theory and reactor-physics problems concerned with reactivity, neutron age and flux distribution, and buckling. B-15 considers natural and enriched uranium, plutonium and thorium cycles and aspects of them, such as economics, burnup and burnable poisons. B-14b papers present long-term economic prospects and the place of nuclear power in the power programs of several specific countries.

Vol. 20, Isotopes in Research (265 pages, $10.00), is limited to session D-6, Production and Use of Isotopes in Research. Twenty of the fifty papers are concerned with production of radioisotopes and labeled compounds. The remainder describe industrial and more basic research applications. Several papers are on stable isotopes.

Vol. 33, Index of the Proceedings (212 pages, $16.50), in addition to conference paper number and author indexes, contains an index of about 10,000 primary subject entries and 40,000 scientific-word entries prepared by Battelle Memorial Institute. The latter index provides multiple entries and cross referencing.



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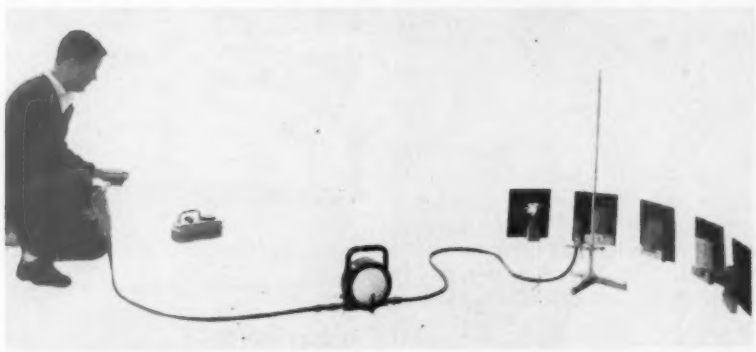

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- ☐ Goertzel & Tralli—Some Math. Methods of Physics—$8.50
- ☐ Hackforth—Infrared Radiation—$10.00

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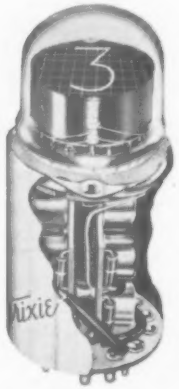
PRODUCTS & MATERIALS

Department starts on page 103

Digital Vacuum Gage

Portable, direct reading, digital vacuum gage (above) reads pressure values and utilizes decade-tube readout system which places decimal automatically. Response time of meter is <2 sec. Instrument has five ranges from 0.01 to 900 microns and reads to one significant digit, ± one-half digit.—Nuclear Metallurgical Enterprises, 1004 United Office Building, Niagara Falls, New York.



Transistor Readout

Low-cost transistor drive module for an indicator tube has ten medium-voltage NPN transistors in a common emitter configuration (above). Each transistor drives one of indicator tube's ten cathodes. Readout modules require only 300 μa and can be triggered by 3-v signals.—Burroughs Corp., P. O. Box 1266, Plainfield, N. J.

Evaporation Detection Unit

Evaporation detection unit concentrates radioactive materials in solution by evaporating liquid portion. Remaining solids can be counted. Liquid capacity is 1,000 cm³ and 90% of all radioactive materials are concentrated on a 2-in. planchet in 2-3 hr. Area of deposition is variable to any diameter from 0.5 to 2 in.—Technical Services Dept., Instrument & Research Division, Nuclear Corp. of America, Denville, N. J.

Low Level Beta Counter

Low level beta counting system (above) has single Amperex counter tube/guard tube configuration and an anticoincidence scaler. This permits large reduction of shielding for backgrounds of 1 cpm or less and provides increased reliability. System is available with T/A Model PT-1R predetermined timer.—Technical Associates, 140 W. Providencia Ave., Burbank, Calif.

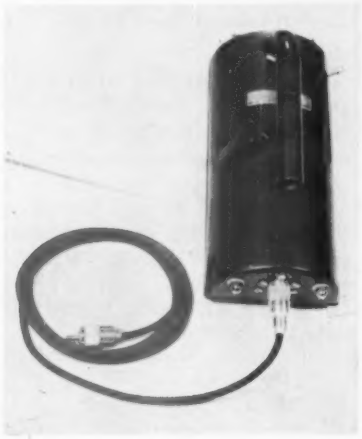
Transistor Spectrometer

Liquid scintillation spectrometer used to assay samples of α- and β-emitting isotopes such as H_3, C^{14} and S^{35} is now available in transistor model (above). Line-voltage regulation and over-all stability are significantly better in transistor model in addition to usual advantages of greater reliability, size and weight reduction, lower power consumption and cooler operation. Price is same as for vacuum-tube

models.—Packard Instrument Co., Inc., P. O. Box 428, La Grange, Ill.

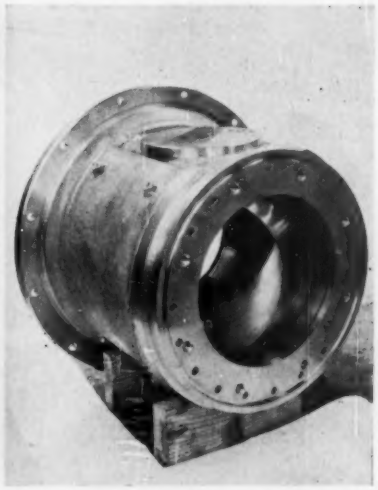
Differential Scanner

Differential scanner (below), a gamma-counting radiometric probe, separates extraneous or background radiation from measured radiation. Leaks in nuclear devices can be detected and evaluated. Portable counting rate-meter or scaler is used for readout. Scanner can be standardized for specific gamma-measurement applications.—Uranium Instruments Co., 126 N. Seventh, Grand Junction, Colo.



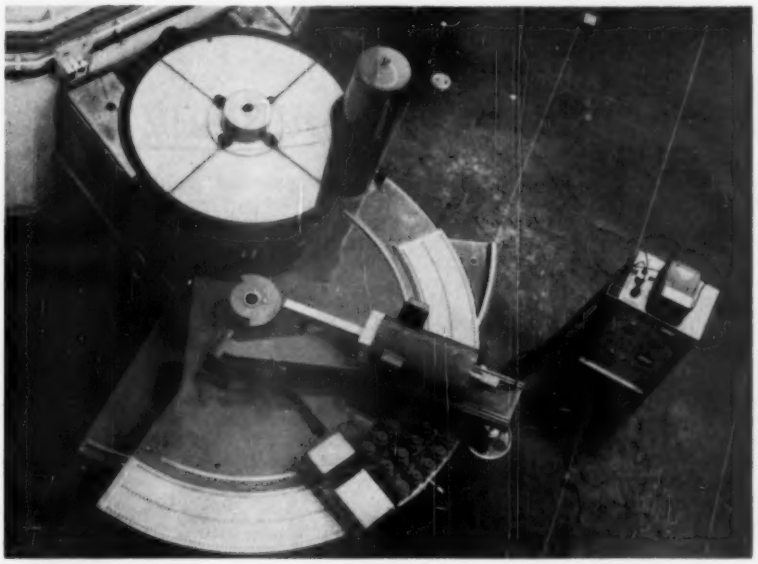
Plastic Film Dust Bellows

Flexible thermoplastic film such as polyethylene, vinyl, Nylon vinyl and Estane are used to fabricate dust bellows (below) which are either fully sealed or permit breathing. Bellows are fabricated by using dielectric heat process to join rings of plastic film alternately on i.d. and o.d. Various gage films are used and bellows of virtually unlimited i.d. and o.d. can be fabricated providing o.d. is at least $\frac{5}{8}$ in. larger than i.d.—A. F. Gagne, Associates, 50 Wall St., Binghamton, N. Y.



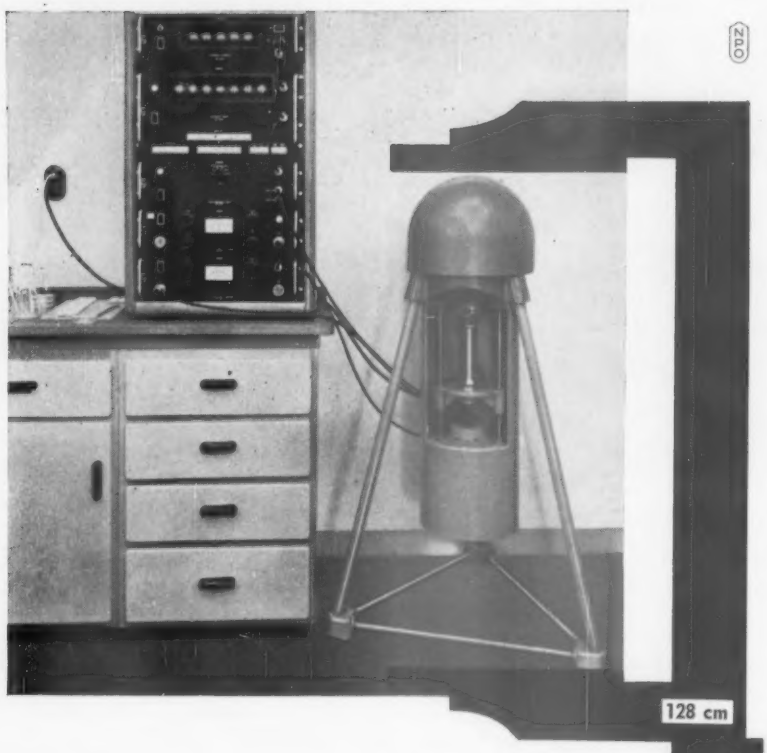
Depleted-U Ball Valve Used as Cask Car Access Port

Ball valve incorporating a 427-lb, 10-in. bore uranium ball forms the access port of the Enrico Fermi cask car which Baldwin-Lima-Hamilton Corp. is building. Actuation time for the valve, which is mechanically operated by remote control, is 300 msec. Continuous machining operation lasted 6 days and reduced a 534-lb uranium ball to its finished shape and weight. Pyrophoric fire was precluded by use of high flashpoint no. 200 coolant oil; in addition, special, extra sharp cutting tools and relatively slow machining surface speed of ~97 fpm were used to reduce heating.—Hydromatics, Inc., 70 Okner Pkwy, Livingston, N. J.



Neutron-Diffraction System

Neutron-diffraction system (above) uses novel drive that enables an automatic scanning of neutrons in very small steps (up to 5-min arc). In this way, counting tube goes through a 130-deg arc within a preselected duration that can be extended up to 1 month. Neutrons of homogeneous energy are produced by reflection on a crystal placed in the center axis of a movable shielding cylinder weighing $2\frac{1}{2}$ tons. Main components are remarkably precise. System is used in conjunction with Garching Atomic Reactor by the Institute for Technical Physics, Munich Technical College.—Maschinenfabrik Augsburg-Nurnburg, W. Germany.



Background	:	**less than 1 count per minute**
Weight	:	**280 kg (620 lbs) only**
Height	:	**128 cm (50 ½ in.) only**

low-level beta counting

Low-level beta counting is brought to an elegant and simple solution by the novel Philips anti-coincidence assembly, type PW 4127, together with its associated electronic equipment.
The assembly comprises two radiation-sensitive elements only, viz. a low-level beta counting tube*), and a single guard tube which replaces the conventional array of dozens of guard tubes hitherto required for low-level work.
By virtue of this unique design tons of shielding material are eliminated; the electronic circuitry is considerably simplified, and hence overall reliability is greatly improved. Reproducibility is guaranteed by the fixed geometry of the sample with respect to the counting tube.
With a background of less than 1 count per minute; it is now possible to measure in a 300 mg sample a beta activity (e.g. Sr^{90} or Tl^{204}) of $(5 \pm 0.5) \times 10^{-12}$ Curie in only one hour.

***) Two types available:**

type 18515 for measuring low-energy beta radiation, with a 1.5 mg/cm² mica window;

type 18516 for general low-level beta work, with a 10 mg/cm² Cr-Fe window.

PHILIPS

nuclear equipment

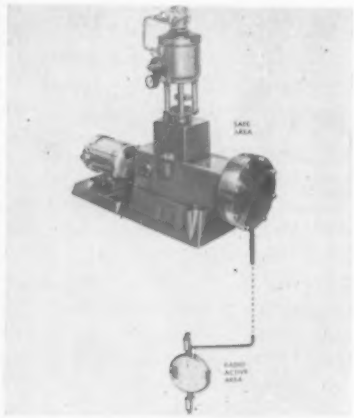
N.V. PHILIPS' GLOEILAMPENFABRIEKEN - EINDHOVEN - HOLLAND

PRODUCTS & MATERIALS

Department starts on page 103

35-mm Film Reader

Semiautomatic 35-mm film reader (above) has resolution $> \pm 1$ micron and full scale accuracy $> \pm 5$ microns. Gaertner stage with a 50 mm × 50 mm range moves three lenses, beam splitters and reticle projectors over three 35 mm films. Three 35 mm projectors project three films onto a screen. Operator can scan any of 3 views of a particle track pattern while seeking correct tracks for measurement.—Hydel, Inc., 223 Crescent St., Waltham 54, Mass.



Radioactive-Fluids Pump

Pumping unit developed for safe handling of high-level radioactive fluids (above) has welded-diaphragm reagent head that can be placed in intensely radioactive remote areas removed from pumping unit. Reciprocating piston within positive-displacement pump forces oil to move a diaphragm back and forth. Pumping unit controls flow of transfer liquid through welded head in the radioactive area, and remote reagent head has stainless-steel diaphragm that isolates transfer liquid from radioactive liquid.—Process Equipment Division, Lapp Insulator Company, 113 Hall St., LeRoy, N. Y.

LITERATURE AVAILABLE

Gamma-ray spectrometry systems. Bulletin 171, 2 pp.; Technical Associates, 140 W. Providencia Ave., Burbank, Calif.

Precision pulse generator. 2 pp.; Interstate Electronics Corp., 707 E. Vermont Ave., Anaheim, Calif.

Pressure and temperature recorders. Catalog 800, 8 pp.; American Machine and Metals, Inc., U. S. Gauge Div., Sellersville, Penna.

Preengineered piping & equip. supports. 96 pp.; Bergen Pipesupport Corp., 50 Church St., New York, N. Y.

Carbon and graphite products. 8 pp.; Speer Carbon Co., St. Mary's, Penna.

Stainless steel; seamless tubing. 15 pp.; Timken Roller Bearing Co., Steel and Tube Div., 1835 Dueber Ave., S. W., Canton 6, Ohio.

Facilities for contract manufacturing services. Paraplegics Manufacturing Co., 10068 Franklin Ave., Franklin Park, Ill.

Safety enclosures. Bulletin A-14, 2 pp.; S. Blickman, Inc., 536 Gregory Ave., Weehawken, N. J.

Photomicrography of metals. Industrial data book, 44 pp.; Eastman Kodak Co., Rochester 4, N. Y.

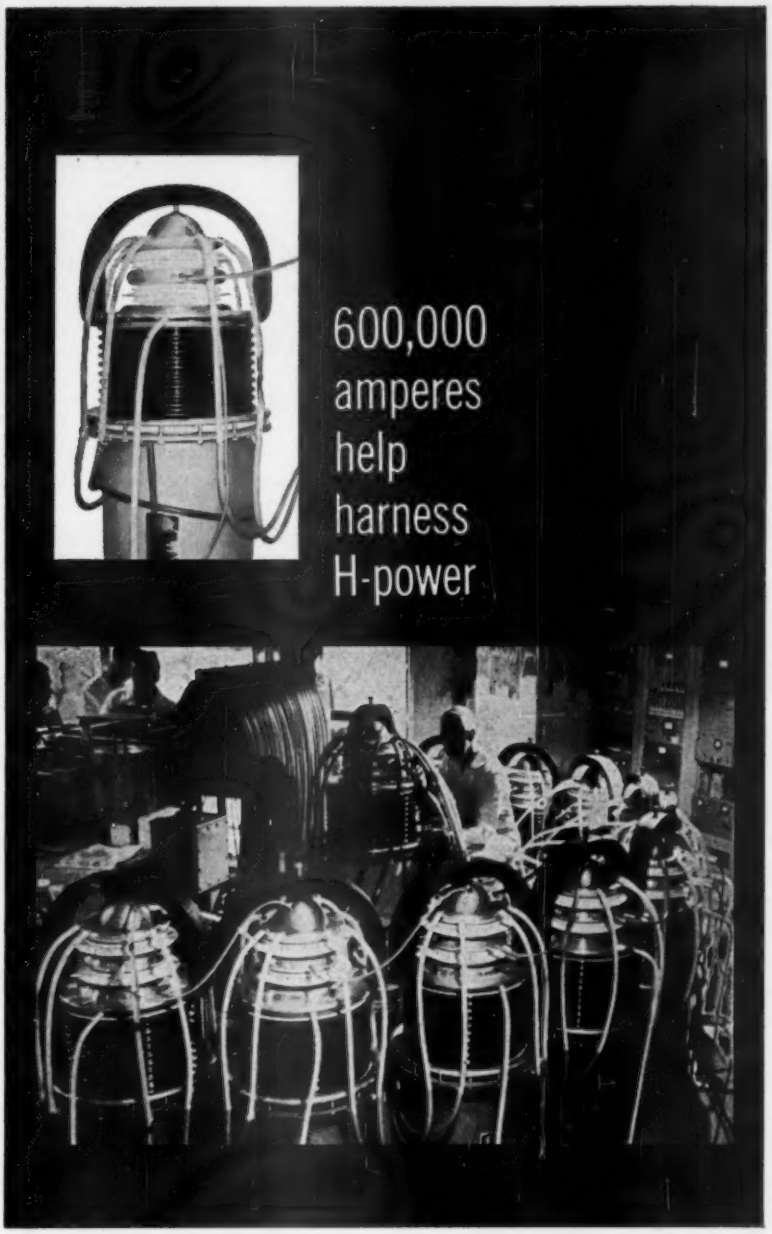
Tube and fitting welder. 4 pp.; Cycl-O-Magic Inc., 1736 N. Second St., Milwaukee, Wisc.

Ultrasonic gages, 8 pp.;
Ultrasonic cleaning. 24 pp.; Branson Instruments, Inc., 37 Brown House Rd., Stamford, Conn.

Multiple frequency ultrasonic cleaner. Bulletin 58, 2 pp.; McKenna Laboratories, 2503 Main St., Santa Monica, Calif.

Protective equipment and apparel. Catalog 60, 25 pp.; Snyder Manufacturing Co., Inc., New Philadelphia, Ohio.

Translations of Soviet nuclear research. 20 pp.; Consultants Bureau



At the historic Geneva Atoms-For-Peace Conference, Los Alamos scientists unveiled **Scylla**—a fusion device used to heat a plasma of ionized heavy hydrogen particles millions of degrees by blasting it with a 600,000-ampere thunderbolt.
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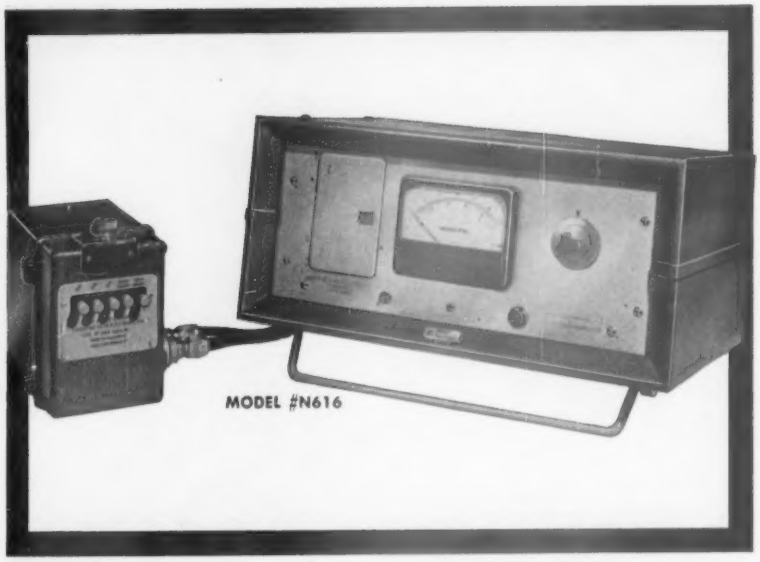

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PRODUCTS & MATERIALS

Department starts on page 103

Enterprises, Inc., 227 W. 17 St., New York 11, N. Y.

Cobalt-60 radiation. 8 pp.; Atomic Energy of Canada Ltd., Commercial Products Div., P. O. Box 93, Ottawa, Canada.

Nuclear instruments. 8 pp.; Borg-Warner Controls Div., Borg-Warner Corp., 3300 Newport Blvd., Santa Ana, Calif.

Radiation monitoring system. 4 pp.; Riggs Nucleonics Corp., 717 N. Victory Blvd., Burbank, Calif.

BeO. 4 pp.;
Sealed isotope capsules. 2 pp.; Curtiss-Wright Corp., Research Div., Quehanna, Penna.

Precision tubing. 4 pp.; Damascus Tube Co., Greenville, Penna.

Atomic energy at Allis Chalmers. 25 pp.; Allis-Chalmers Manufacturing Co., Atomic Energy Div., Milwaukee 1, Wisc.

Vitro designs. Company brochure. 36 pp.; Vitro Engineering Co., 225 Park Ave., New York 3, N. Y.

Low inductance, energy storage capacitors. Bulletin 191, 11 pp.; Cornell-Dubilier Electric Corp., S. Plainfield, N. J.

Large polyolefin moldings. 4 pp.; American Agile Corp., P.O. Box 168, Bedford, Ohio.

Critical piping for the nuclear age. Bulletin 60-A, 17 pp.; Midwest Piping Co., Inc., 1450 S. Second St., St. Louis 4, Mo.

Reactive and precious metals. 4 pp.; Consolidated Reactive Metals Inc., 115 Hoyt St., Mamaroneck, N. Y.

Kennametal heavy tungsten alloys. 10 pp.; Kennametal Inc., Latrobe, Penna.

Stainless type-304 with boron^{10}. 2 pp.; The Carpenter Steel Co., Reading, Penna.

Tritium foils and targets. 1 p.; United States Radium Corp., Morristown, N. J.

Diaphragm valves. 2 pp.; Aqua-Matic, Inc., 2412 Grant Ave., Rockford, Ill.

Engineers' guide to silicones. 12 pp.; Dow Corning Corp., Midland, Mich.

Thermocouple data calculator. West Instrument Corp., 4363 W. Montrose Ave., Chicago 41, Ill. Price $2.00.

Three dimensional closed-circuit tv. Data sheets 6-148, -143, -139, 6 pp.; Kin Tel, Box 623, San Diego 12, Calif.

Precision instruments for industry. Catalog 1040, 8 pp.; Illinois Testing Laboratories, Inc., 420 N. La Salle St., Chicago 10, Ill.

Nuclear equipment. Abridged catalogue 2, 24 pp.; Philips' Gloeilampenfabrieken, Scientific Dept., Eindhoven, Holland; In U. S. available from Philips Sales Offices.

Radioactivity scaler-ratemeter. Bulletin 45, 2 pp.;
Portable, transistor α, β, γ survey meter. Bulletin 701, 2 pp.;
α, β, γ detectors & accessories. 48 pp.;
Neutron detector catalog. 34 pp.; Anton Electronic Laboratories, Inc., 1226 Flushing Ave., Brooklyn 37, N. Y.

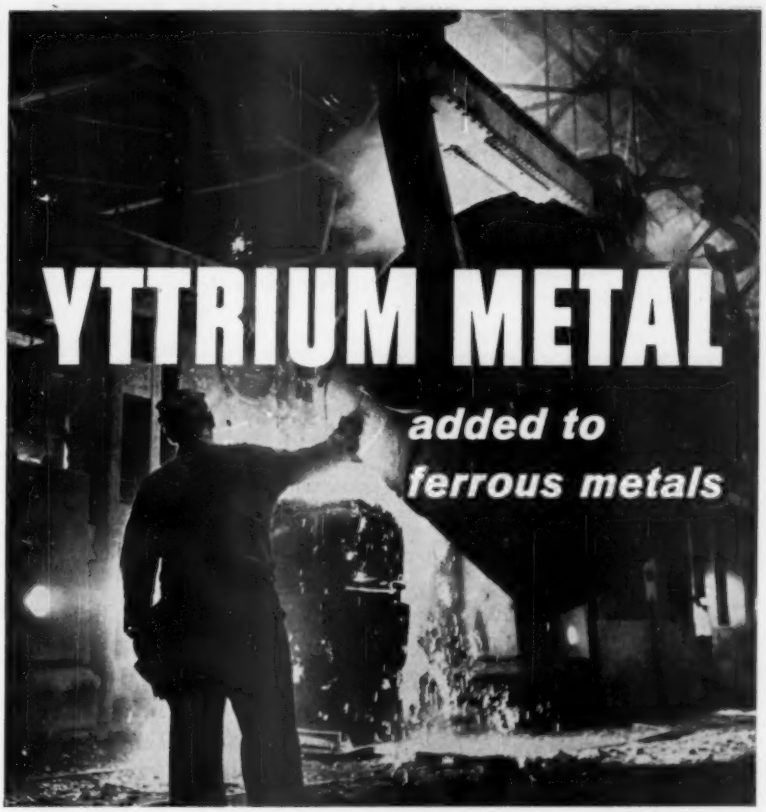
Transistor analyzer & instruments low level gamma counting. 6 pp.; Radiation Counter Laboratories, Inc., 5121 W. Grove St., Skokie, Ill.

Dosimeter, survey meters and probes. 12 pp.;
Medical radiation instruments. 8 pp.;
Thin-window flow counter. 2 pp.; The Victoreen Instrument Co., 5806 Hough Ave., Cleveland 3, Ohio.

Transistor laboratory monitor. 1 p.;
Marinelli scintillation counting system. 1 p.; Atomic Accessories Inc., 811 W. Merrick Rd., Valley Stream, N. Y.

Null detector & d-c microvoltmeter. 2 pp.; Keithley Instruments, Inc., Cleveland 6, Ohio.

Multi- and special-purpose counters. 6 pp.; Hewlett-Packard Co., 1275K Page Mill Road, Palo Alto, Calif.



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INDUSTRY NOTES

● No less than four new firms have been created in recent weeks. **McLain Rodger Associates** has been established at 921—60th Pl., Downers Grove, Ill., a Chicago suburb, for consulting in reactor design and operation, nuclear fuel cycles and radioactive-waste disposal. Partners in the venture are Stuart McLain and Walton A. Rodger, both formerly of Argonne National Laboratory. . . . **Electronucleonics,** P. O. Box 707, Caldwell, N. J., has been organized to exploit the potential of ultra gas centrifuging as applied to gas separation, isotope separation, molecular pumping and such outer-space applications as environment simulation and propulsion; Electronucleonics has begun development of the first in a series of prototypes of a large ultra gas centrifuge. . . . **Ray Data Corp.,** 1078 E. Granville Rd., Worthington, Ohio (formerly Foster Engineering Corp.), has been founded by George Foster, former vice-president at Industrial Nucleonics; Ray Data will stress development of instrumentation (primarily nonradioactive) for monitoring industrial processing equipment (sensing temperatures, magnetic properties, etc.). . . . **York Industrial Plastics, Inc.,** York, Pa., will offer a complete line of pipes and fittings, valves and pumps lined with a German-developed thermosetting plastic which is high-temperature and chemical resistant; it also has a shielding potential for nuclear reactors, the firm feels.

NEW BUSINESS. A $700,000 contract for supply of high-purity nuclear graphite has been awarded by AEC to **National Carbon Co.,** division of Union Carbide Corp. It covers 120 graphite columns measuring 16 in. sq and 20 ft long for the Experimental Gas-Cooled Reactor under construction at Oak Ridge; delivery is to be completed in one year. . . . **Biochemical Procedures, Inc.,** has been awarded a contract by AEC for evaluation studies of radioactive-waste systems; specifically, Biochemical will evaluate the performance of special distilling apparatus designed for use in waste processing, working chiefly at the National Reactor Testing Station, Idaho Falls. . . . The German State of North Rhine-Westphalia has ordered construction of a laboratory for radioactive solids by **Leybold Hochvakuum Anlagen GmbH,** Cologne; it will be operated by the Institute for Reactor Materials near the State's Atomic Research Center, Jülich.

FINANCIAL. The latest in a series of acquisitions has been completed by **Victoreen Instrument.** It is **Electronic Products,** Mt. Vernon, N. Y., a 50-man organization supplying radiation-detection instruments for Polaris-type submarines and medical use (for example, an instrument permitting precise placement of cobalt probes into the body). Victoreen said the new division would add $5-million-plus in annual sales to the company's expected total of $20-million this year. . . . **American Electronics** reported a record first quarter, ended March 31, with earnings of $183,795 (21¢/share) on sales of $7,231,996. President Philip W. Zonne predicted full-year earnings would reach $1-million ($1.11/share) on sales of $30-million; 1959 earnings were 70¢/share on sales of $25-million. . . . **Royal Industries** reported that its atomic-energy sales, increasing rapidly, make up a "major portion" of a 26% increase in backlog as of Apr. 26 over Dec. 31 ($11,600,000, as compared with $9,200,000). The company's Vard div. claims the most completely equipped test facilities in the U. S. for the evaluation of new designs and production of control-rod mechanisms; it supplies the Naval reactor program and commercial reactors. Royal's earnings for the quarter ended March 31 were $84,093 on sales of $2,856,163. . . . **Anton-Imco Electronic Corp.** reported soaring earnings for the quarter ended March 31—$124,090, or 50 cents/share, on sales of $2,505,285; '59 quarter earnings were $5,692 on sales of $1,565,357.

EXPANSIONS. A substantial expansion of its capacity for beryllium metal production is planned by **Brush Beryllium**—expansion of monthly production of vacuum-cast beryllium billets from 12,500 to 24,000 lbs; and of beryllium hydroxide capacity from 35,000 lb to 60,000 lb/month (beryllium content). . . . **American Electronics** has broken ground for a 100,000 sq ft research, development and manufacturing complex in Fullerton, Calif.; it is scheduled for completion in September at a cost of $1.5-million. . . . **Eitel-McCullough, Inc.,** manufacturers of electron power tubes, is adding three buildings (83,000 sq ft)—two at San Carlos, Calif., one at Geneva, Ill.

NEWSMAKERS

The Distinguished Service Award of the U. S. Office of Civil and Defense Mobilization has been awarded to **Lewis V. Spencer,** physics professor at Ottawa Univ., Kan., for "outstanding contributions to the science of radiation shielding and to the Nation's fallout shelter program." At the National Bureau of Standards Spencer directed a program which developed basic theories and procedures for calculating radiation penetration of materials and structures. He is chairman of the radiation-shielding committee of the National Academy of Sciences and an NBS consultant.

Spencer

Floy W. Smith has been named reactor operations chief at the new Nuclear Science Center, Texas A & M College System. Smith had been supervisor of the nuclear-engineering and physics group, Chance Vought, Dallas.

AEC Consultant and Johns Hopkins Professor **Abel Wolman** has been named to head the new Radiation Control Advisory Board in Maryland. The nine-man Board, which also includes Russell Morgan of Johns Hopkins Hospital, will be advisory to the State government; the State's Health dept. has actual control and inspection authority over radiation sources.

C. Sharp Cook has been appointed head of the Nucleonics div. of the U. S. Naval Radiological Defense Laboratory, San Francisco. Since 1953, Cook had been head of the Nuclear Radiation branch and its successor, the Radiation Characteristics and Effects branch. The lab has one of the largest radiation-effects programs in the U. S.

Cook

John L. Kuranz, vice-president, Nuclear-Chicago Corp., left New York on May 18 for a three-week, round-the-world survey of nuclear installations. He will survey existing and proposed radioisotope labs, particularly in Asia (Tel Aviv, Teheran, Karachi, Bombay, Djakarta, Saigon, Manila and Tokyo).

Lloyd V. Berkner, president of Associated Universities, Inc., which operates Brookhaven National Laboratory for AEC, has been elected to a four-year term as treasurer of the National Academy of Sciences.

Glenn W. Oyler has been named head of the Welding Research and Development dept. at M & C Nuclear. In his new post, he will be responsible for the conception and development of new methods and techniques for assembling nuclear fuel elements and allied components by welding. He joined M & C from Linde Co., where he was sales-development chief, Electric Welding div.

Oyler

Col. Gordon B. Page will succeed **Col. Donald G. Williams** as assistant director for Army reactors, AEC, on July 1. Page, who is on the staff and faculty of the Army War College, Washington, D. C., will report to Reactor Development Director Frank Pittman. Williams has been transferred to Honolulu as assistant division engineer, Pacific Ocean div., Army Corps of Engineers (Hawaii, Okinawa, Korea, etc.).

Chase Manhattan Bank has promoted **Paul F. Genachte,** its atomic energy director, to vice-president. Genachte has taken on a "second hat" as chief marketing officer for the International dept., supervising the Bank's activities related to the European Common Market and Free Trade Assn.; he retains his nuclear post.

U. S. Radium has promoted three top officials: **C. C. Carroll,** former head of the Bloomsburg, Pa., plant, to new-products manager at Morristown, N. J., headquarters; H. C. Clapham to succeed Carroll at Bloomsburg; and **J. G. MacHutchin,** to manager, research and development, at Bloomsburg. The Pennsylvania facility produces dials, panels, nameplates, etc.

Two Babcock & Wilcox people have left to join other organizations. **John**

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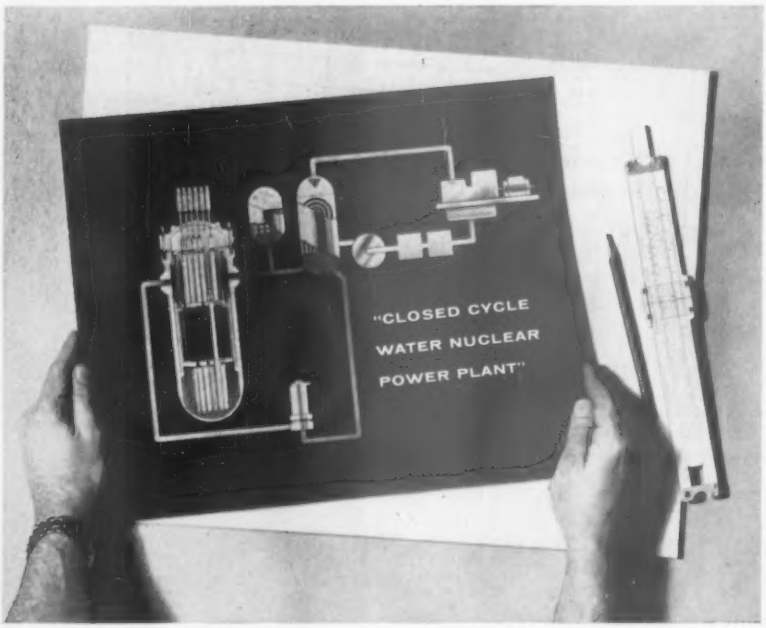

330-1 REACTOR—With a reactor vessel and closure head weighing 418 tons, standing 41 feet high and having a 12 foot ID, the engineers and scientists at the Commercial Atomic Power Department visualize a power system that can produce 360 gross electrical MW. This is the scope of planning now in progress at APD. You can take part in this or other phases of the rapidly expanding commercial nuclear power field where your talent can be applied to the problems of making nuclear energy competitive with other forms of power.

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Engineers—Materials development for fuel element prototypes including fabrication and testing of aluminum, zirconium and stainless steel alloys. B.S. degree in Metallurgy and preferably nuclear experience.

Engineers—Instrumentation and control section (a.) Analytical and design work on digital computer programs and techniques. M.S. or E.E. degree and several years experience. (b.) Development, design and application of neutron flux and radiation sensors and associated circuitry. Degree in electronics or physics with minimum of 4 years related experience.

Scientists and Engineers who want to make the transition to the expanding field of commercial atomic power with a company that is a leader in the field, write to: Mr. C. S. Southard, Westinghouse Atomic Power Division, P.O. Box 355, Dept. W-87, Pittsburgh 30, Pa.

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NEWSMAKERS *starts on page 111*

E. Brennan has left the New York office—where he was staff assistant reporting to W. T. Moore, Atomic Energy div. manager, and L. N. Perry, vice-president of the division—to join Garlock, Inc., Palmyra, N. Y., as assistant to the president. **Tom L. Gallagher,** a reactor physicist, has joined the nuclear-engineering staff at Internuclear Corp.

Two important posts have been filled in the Nuclear Electronics lab, Hughes Aircraft Co. **Marvin Fox,** former vice-president for foreign operations at Internuclear Co., has joined the lab as a senior staff physicist. **Elmer L. Zimmerman,** formerly head of critical-experiment units at Atomics International, has been named head of nuclear circuitry research. Fox will work with intense neutron pulsing, with the application of nuclear reactors to unconventional power requirements in missile systems and with Hughes' remote-control robots.

Robert S. Shankland, Ambrose Swasey professor of physics at Case Institute of Technology, has been elected president, Associated Midwest Universities, succeeding Laurence L. Quill, Michigan State Univ.

A well-known nuclear and mathematical physicist, **Charles L. Critchfield,** has accepted the vice-presidency for research at Telecomputing Corp.; he had been, since 1955, director of scientific research, Convair div., General Dynamics. With George Gamow, he wrote the book "Theory of Atomic Nucleus and Nuclear Energy Sources" in 1947.

Critchfield

Public relations director **Garland C. Ladd,** Atomics International, has been promoted to assistant to Chauncey Starr, AI president.

Astra, Inc. has added three to its staff: **Robert L. Dough,** formerly with the North Carolina State faculty and the Atomic Power div., Newport News Shipbuilding and Dry Dock Co.; **Robert R. Liguori,** also of the N. C. State faculty; and **Andrew Lowery,** formerly of Wright Machinery Co.

NUCLEAR CAMPUS

● **Univ. of Michigan** has raised $1,705,000, or two-thirds of its $2,500,000 goal, in its campaign for the Memorial-Phoenix Project on atomic research. The funds will be used to continue the Project for another five years; over its 12 years of operation to date the Project has supported 185 research investigations in 15 schools and colleges of the University.

● The Mississippi Legislature has authorized the issuance of $1.5-million in bonds to finance the establishment of a research center—including nuclear research—by the **Univ. of Mississippi.** Construction of the center will be directed by a State Building Commission, chaired by Gov. Ross R. Barnett.

● **Univ. of Wisconsin** expects completion of a 10-kw, pool-type training research reactor by late this year—to be installed on campus by General Electric at a cost of $266,000, including $150,000 from AEC. The unit will be housed in the Reactor Laboratory on the engineering campus.

● **Univ. of Virginia** has completed its 1,000-kw pool reactor and was expected to put it into operation by the end of June. The reactor is located 2,000 ft west of Charlottesville in an abandoned reservoir.

● **Univ. of Rochester** is adding a $522-000 wing to the nuclear annex of its Medical Center; AEC is paying all but $4,000 of the cost.

COURSES. A graduate training program emphasizing the **use of radiation in the investigation of biological and medical problems** will be initiated this summer at the Univ. of California Medical Center, Los Angeles. Contact chairman, Dept. of Radiology, School of Medicine, UCLA, Los Angeles 24.

UCLA is also offering a two-week short course in the **theory and applications of plasma physics,** July 11–22. Contact H. L. Tallman, Physical Sciences Extension, Rm. 6501, Engineering Bldg. II, UCLA, Los Angeles 24.

Taft Sanitary Engineering Center, Cincinnati, is offering **radionuclides in food,** Sept. 12–23; **basic radiological health,** Oct. 3–14; **radionuclide protection** and **radiological health for x-ray technicians,** Oct. 17–21; and **x-ray protection,** Oct. 24–28.

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NUCLEONICS

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NUCLEAR CALENDAR

July 21–27—3rd International Conference on Medical Electronics, London. Contact Secretary, Institution of Electrical Engineers, Savoy Place, London W. C. 2, England, or Lee B. Lusted, Dept. of Radiology, Univ. of Rochester School of Medicine, Rochester 20, N. Y.

Aug. 11—AEC information meeting on small reactors, Oak Ridge. Contact R. A. Charpie, ORNL, Box 4, Oak Ridge.

Aug. 15–17—International Conference on Organic Scintillation Detectors, sponsored by Univ. of New Mexico, on its campus, Albuquerque, N. M. Fundamental review, new advances and theories, and applications in natural sciences, medicine and industry. Several commercial exhibits of instruments used in the field will be available; 17th, tour of Los Alamos Scientific Lab. Contact Guido H. Daub, Chemistry dept., Univ. of New Mexico, Albuquerque.

Aug. 17–19—University Reactor Conference, Gatlinburg, Tenn. Sponsored by Oak Ridge National Laboratory, Oak Ridge Institute of Nuclear Studies, AEC and Oak Ridge Section, American Nuclear Society. Contact W. W. Grigorieff, ORINS, Box 117, Oak Ridge, Tenn.

Aug. 22–26—Symposium on Thermonuclear Plasma Physics, Gatlinburg, Tenn. Sponsored by Oak Ridge National Laboratory, Oak Ridge Institute of Nuclear Studies and AEC. Contact D. D. Cowen, P. O. Box X, Oak Ridge.

Aug. 23–26—Western Electronic Show and Convention, Los Angeles (*Memorial Sports Arena, Exposition Park*). Contact Ted Shields, 2411 W. 8th St., Los Angeles 57, Cal.

Aug. 25–Sept. 1—10th Annual International Conference on High Energy Physics, Rochester, N. Y. (*Univ. of Rochester*). Contact Charles Cole, Office of Public Information, Univ. of Rochester, River Campus, Rochester 20, N. Y.

Aug. 29–31—U. S. Public Health Service Symposium on Water Quality Measurement and Instrumentation, Cincinnati, Ohio (*Sanitary Engineering Center*). Emphasis on automatic instrumentation. Contact Director, Robert A. Taft Sanitary Engineering Center, 4676 Columbia Pkwy., Cincinnati 26.

Sept. 13–15—Fifth International Instruments and Measurements Conference, including section on nuclear instrumentation, and an exhibition of commercial instrumentation, Stockholm. Contact H. von Koch, Royal Institute of Technology, Stockholm 70, Sweden.

Sept. 26–30—Fall Instrument-Automation Conference and Exhibit and 15th Annual Meeting of Instrument Society

of America, New York City (*Coliseum*). Contact W. F. Minnick, Jr., ISA, 313 6th Ave., Pittsburgh 22, Pa.

Sept. 27–30—Power Systems Conference, American Rocket Society, Santa Monica, Cal. (*Miramar*). Full day on systems for auxiliary nuclear power (SNAP). Sponsored by Air Force, Army, Navy, AEC, National Aeronautics and Space Administration. Contact Nathan W. Snyder, Institute for Defense Analysis (ARDA div.), Universal Bldg., Washington, D. C.

Oct. 3–5—Seventh Annual National Meeting of Professional Group on Nuclear Science, Institute of Radio Engineers. Featuring nuclear applications of solid-state detectors and low-noise amplifiers. Fifty-word abstracts are due Aug. 1. Contact H. E. Banta, Oak Ridge National Laboratory, P. O. Box X, Oak Ridge, Tenn.

Oct. 11–14—Symposium on Inelastic Scattering of Neutrons in Solids and Liquids, sponsored by International Atomic Energy Agency, Vienna. Contact J. Burt, IAEA, United Nations, New York.

Oct. 12–14—Fourth Conference on Analytical Chemistry in Nuclear Reactor Technology and First Conference on Nuclear Reactor Chemistry, Gatlinburg, Tenn. Abstracts of 500 words due by Aug. 1. For analytical chemistry meeting contact C. D. Susano, Oak Ridge National Laboratory, P. O. Box Y, Oak Ridge, Tenn. For reactor chemistry meeting contact W. R. Grimes, same address.

Oct. 12–14—Combined meeting: Fourth Conference on Analytical Chemistry in Nuclear Reactor Technology, and First Conference on Nuclear Reactor Chemistry, sponsored by Oak Ridge National Laboratory, to be held concurrently, Gatlinburg, Tenn. Analytical Chemistry meeting focus on instrumentation and methods for determination of minor and trace components in fuels, coolants, moderators; Chemistry meeting will stress chemical behavior of reactor materials rather than engineering applications. Contact: (for former) C. D. Susano, (for latter) W. R. Grimes, ORNL, Box Y, Oak Ridge, Tenn.

Dec. 11–16—American Nuclear Society–Atomic Industrial Forum joint meeting, San Francisco (*Mark Hopkins* and *Fairmont*). 12–15th Atomfair West, first West Coast nuclear industrial exposition (*Masonic Memorial Building*). Contact W. Kelly Woods, Vallecitos Atomic Laboratory, Pleasanton, Calif., for ANS program; Edwin Wiggin, AIF, 3 E. 54 St., N. Y. 22, for Forum program; Dan Scherer, AIF, for Atomfair. 11–14—8th Hot Laboratory and Equipment Conference. Paper summaries due May 16. Contact James R. Lilienthal, Los Alamos Scientific Laboratory, P. O. Box 1663, Los Alamos, N. M.

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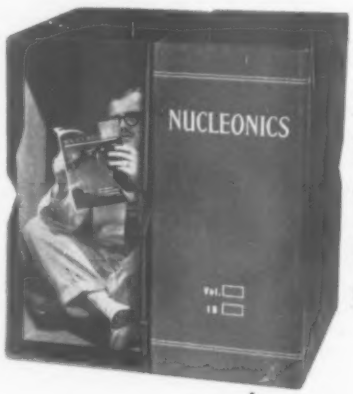

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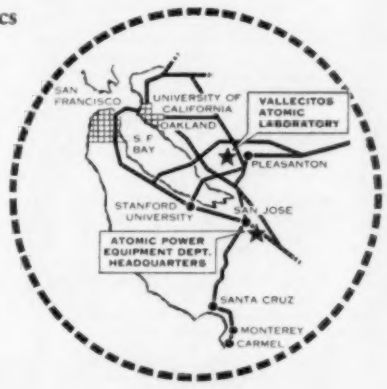

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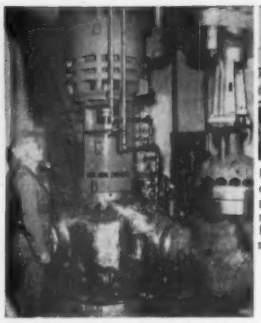

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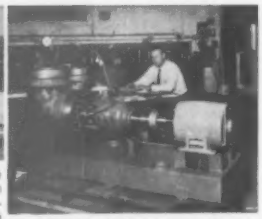

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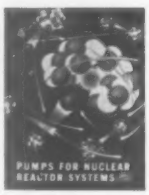

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INDEX TO ADVERTISERS

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Advertising Council 46
Alco Products, Inc. 41
American Machine & Foundry Co., Atomics Division 79
American Smelting & Refining Company, Federated Metals Division 39
American Tradair Corporation, Ekco Electronics Ltd. 108
Anton Electronic Laboratories, Inc. 77
Arapahoe Chemicals, Inc. 74
Argonne National Laboratory . 47
Atomics Div. of American Machine & Foundry Co. 79
Atomics International, A Division of North American Aviation, Inc. 92, 93
Babcock & Wilcox Company Boiler Division 1
Baird-Atomic, Inc. 69
Barnstead Still & Sterilizer Co. 6
Biochemical Procedures 37
Bristol Company, The 36
Bristol Siddeley Engines Limited 12
Budd Company, Space Atomics Division 15
CBS Laboratories, A Division of Columbia Broadcasting System, Inc. 71
Central Research Laboratories, Inc. 81
Columbia-Geneva Steel 10, 11
Cornell-Dubilier Electric Corporation 107
Corning Glass Works 115
Crystals Division Isotopes, Inc. . 110
Damascus Tube Company 43
Darling Valve & Manufacturing Company 18
Elcor Inc. 120
Fisher Governor Company 13
Franklin Systems, Inc. 74
General Atomic Division of General Dynamics 35
General Electric Company, Knolls Atomic Power Laboratory 116
General Mills-Nuclear Equipment Dept. 9
Hamner Electronics Co., Inc. 2nd Cover
Harshaw Chemical Company, The 8
Haws Drinking Faucet Co. 101
High Voltage Engineering Corporation 95
Isomet Corporation 87
Lawrence Radiation Laboratory of the University of California 116
Leeds and Northrup Co. 42
Linde Company, Division of Union Carbide Corporation . 121
Lockheed Nuclear Products, Georgia Div. . . . . 3rd Cover
Los Alamos Scientific Laboratory 99

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Magazine File Company 116
Martin Company, The 5
McGraw-Hill Book Co. 104
Michigan Chemical Corporation . 109
Moeller Mfg. Co., Inc. 87
National Carbon Company, Division of Union Carbide Corporation . . . . . 4th Cover
Nuclear-Chicago Corp. 75
Nuclear Data, Inc. 85
Nuclear Development Corporation of America 20
Nuclear Enterprises, Ltd. 120
Nuclear Measurements Corp. . . 73
Nucleonics Week 88
Peerless Pump Division, Food Machinery & Chemical Corp. . 120
Philips Gloeilampenfabrieken N. V. 106
Physical Sciences Corporation . . 114
Picker X-Ray Corp. 19
RCA Service Company, a Division of Radio Corp. of America 7
Radiation Counter Laboratories, Inc. 33
Radiation Instrument Development Laboratory, Inc. 38
Radiochemical Centre, The 113
Research Laboratories United Aircraft Corporation 14
Saint-Gobain 34
Stokes Corporation, F. J. . . 48, 111
Surety Rubber Company, The . . 114
Tennessee Coal & Iron 10, 11
Texas Instruments Incorporated, M&C Nuclear Inc. (A Subsidiary) . 2
Tracerlab, Inc. 87
United States Pipe & Foundry Co., Steel and Tubes Division 16, 17
United States Steel Corporation 10, 11
United States Steel Export Company 10, 11
Varian Associates, Inc. 122
Veeco Vacuum Corp. 80
Vitro Engineering Company, A Subsidiary of Vitro Corporation of America 83
Wall Tube & Metal Products Company 98
Westinghouse Atomic Power Division 112
Worthington Corporation . . . 44, 45

●

PROFESSIONAL SERVICES . . 110

CLASSIFIED ADVERTISING
F. J. Eberle, Business Mgr.

EMPLOYMENT OPPORTUNITIES 117–119
Atomic Personnel, Inc. 119
Esquire Personnel 117
General Atomic Div., General Dynamics 119
General Electric Co. 119
General Nuclear Engineering Corp. 117
Internuclear Co. 118
Israel Atomic Energy Commission 117
Lawrence Radiation Laboratory . 118
Monarch Personnel 117, 119
Reactor Development, U. S. Atomic Energy Comm. . . 117, 119

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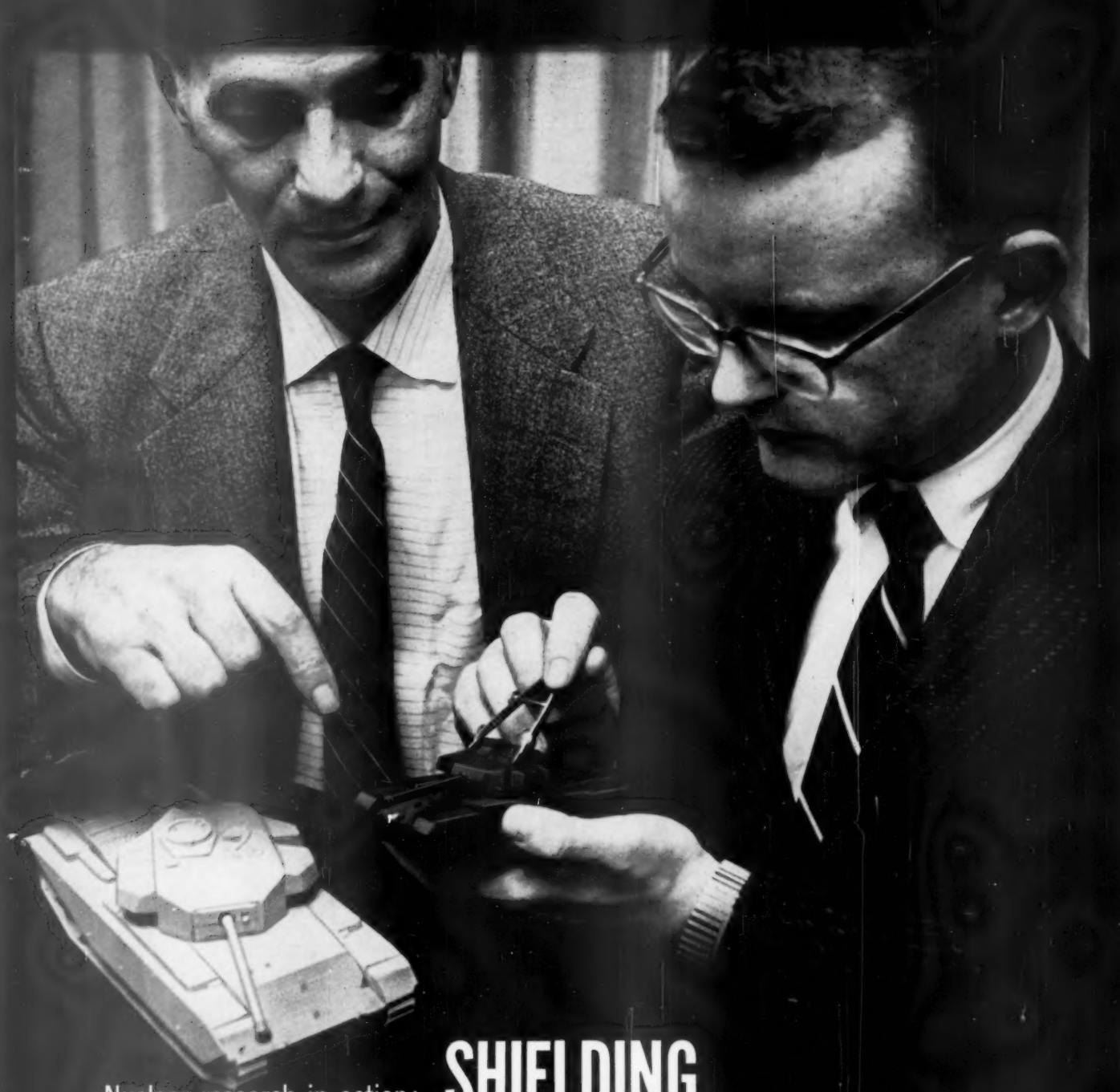

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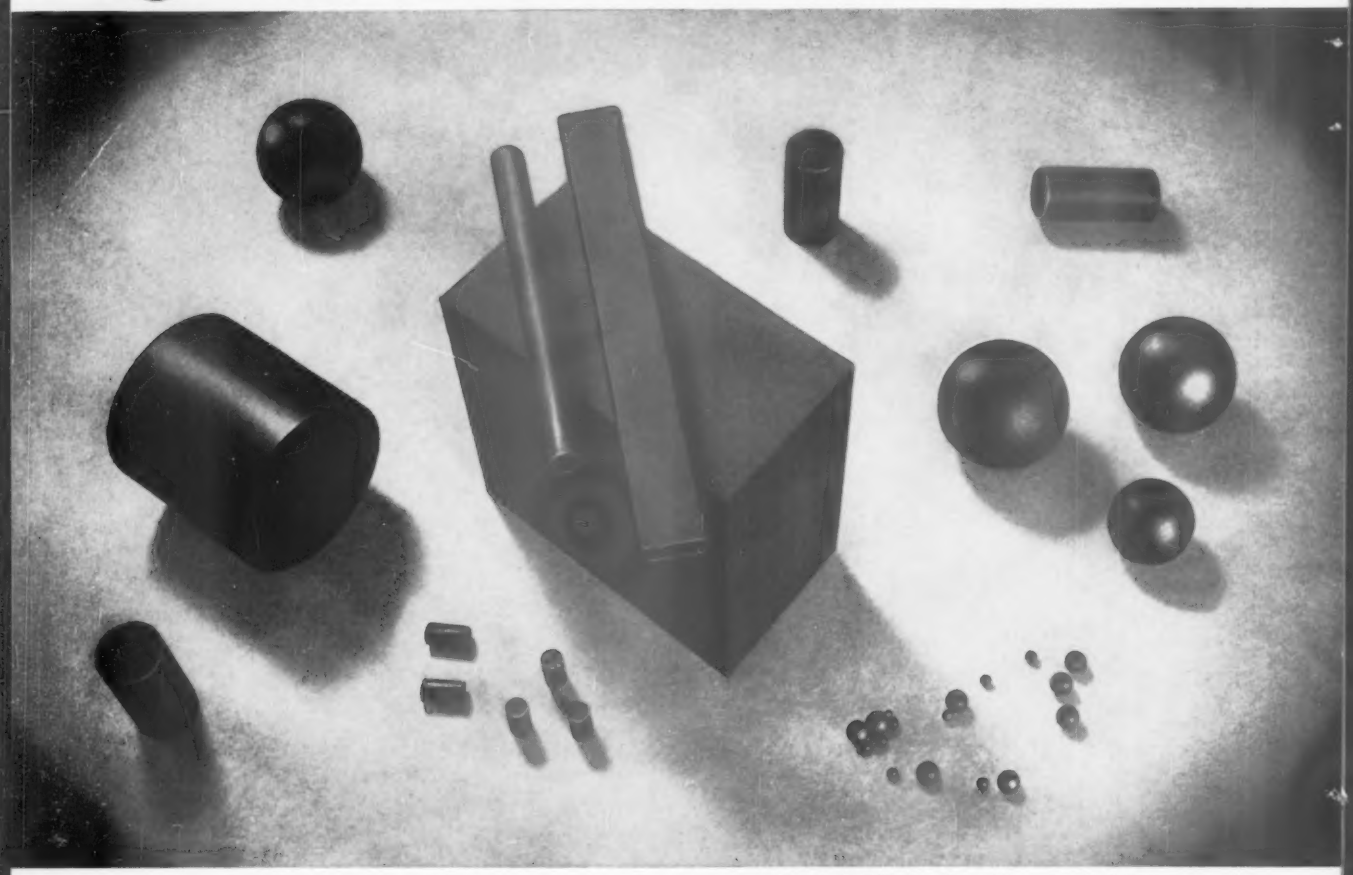

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